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MOTION PICTURE PROJECTION

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MOTION PICTURE PROJECTION

By T.homas O'CONOR SLOANE, Ph.D.; LL.D.

Author of "Home Experiments in Science," "Standard Electrical Dictionary," "Arithmetic of Electricity," and many other Books. Associate Editor of "Science and Invention," and "Practical Electrics."

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PREFACE

THOSE of us who have witnessed the marvellous development of the great motion picture industry, who have perhaps played in our childhood with the strangely named toys, which produced the crude effects of movement of a few printed figures on a short strip of paper, have lived through the most astonishing drama of all that the moving picture world has produced. Its own development to one of the principal industries of the world is a great romance. It is a romance told by thousands of films all over the civilized world; every film is a short chapter in the great story.

The modern motion picture projection machine has grown up from the old tin magic lantern. It has become a marvel of mechanical perfection. Every movement is precise. It deals with minute quantities, which are magnified to colossal dimensions on the distant screen, establishing a condition for showing the smallest error or imperfection in the mechanism. The projection of the minute film picture is a severe test for the mechanism of the projection machine.

This is the perfection of mechanism. Other things are to be noted. The optical system is to be of the best. A picture smaller than a postage stamp is magnified to a width of twelve or fifteen feet and the lens maker has to exercise his best skill to secure a flat image without a trace of aberration.

The intermittent movement has to be as precise as the mechanism of the dividing engine. When the Swiss watch makers developed the stop-movement to protect the mainsprings of their watches, they could not foresee the role it was to play. For on it depends the production of moving pictures all over the habitable world.

Electricity appears also in the work. The operator no longer has to turn the wearying crank for hours at a time. Electricity does it for him.

The projection of motion pictures is a process involving the perfection of mechanics, of optics, and of electricity.

Realizing all this the author lays down his work and calls it finished, when it is really but begun. He has done his best to present the wonderful story of motion picture projection from the aspect of its practical operation. He is modest enough to realize his relation to the immensity of the subject; he is sanguine enough to hope that the book will please the reader.

The sincere thanks of the author are due to such exponents of the art, as Herbert Griffin of the Power Company, J. H. Hallberg of the United Theatre Equipment Company and William Francke of the Precision Machine Co., Inc.

Uniform courtesy and assistance from the best minds in the profession have made the labor a pleasure.

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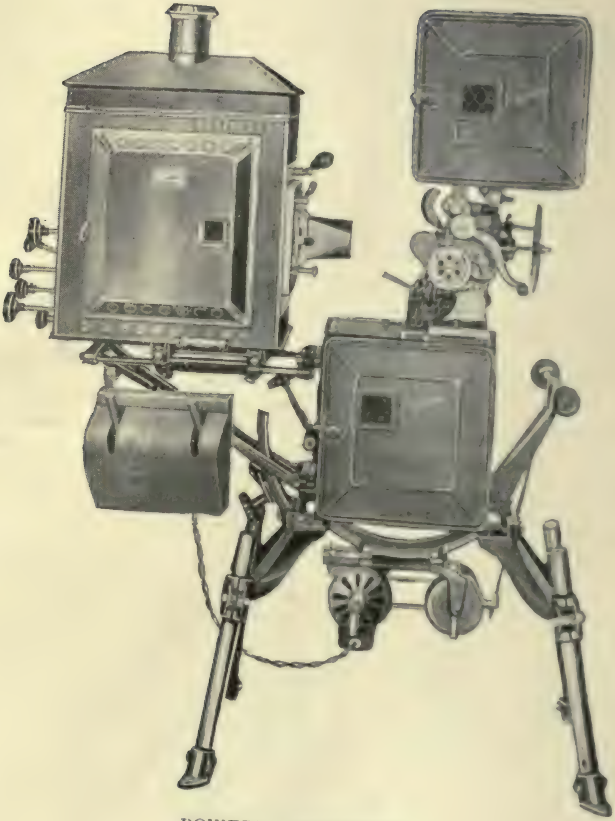


POWER'S PROJECTOR

CHAPTER I

Persistence of Vision

THE motion picture depends for its production upon a quality of the eye, called persistence of vision.

Our power of seeing, which is vision or sight, is due to the action of light on the retina of the eye. The retina in general terms is the inner surface of the rear portion of the eyeball. Here are a mass of sensitive nerves, which are affected by light, and which by other nerves communicate with the brain.

In the pupil of the eye are the lenses, and they project a picture on the retina exactly as the stereopticon projects a picture on the screen. The instant the light is cut off from a stereopticon the picture on the screen vanishes. In the case of the optic nerves it is different. A picture produced on the retina continues to affect the nerves of sight for about a fifth of a second after the picture, as we are calling it, ceases to fall on the retina. If we close the eye the image or rather its effects on the nerves of the retina will continue for the very short period of about the above portion of a second.

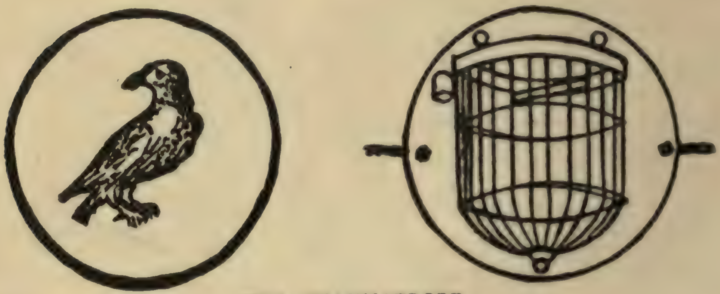
It is on this persistence of vision for the fifth of a second that the motion picture depends for its wonderful illusion and life.

Examples of Persistence of Vision

There are many examples of this quality of the eye. If a stick of wood, with a glowing end, or if a piece of lighted punk, such as used by exhibitors of fireworks, is whirled about, it will seem to make continuous bright lines in the air. The appearance is much more striking if done in the dark than if in broad daylight. It is the persistence of vision, which causes the end of the glowing stick or piece of punk to look like a line of fire.

The Thaumatrope

If a round piece of cardboard, the size of a half dollar, has a couple of short pieces of thread attached to opposite extremities of its diameter, it can be caused to turn rapidly by twisting the threads first one way and then the other, between the fingers of the two hands. If now a bird cage has been drawn on one side of the disc of cardboard, and a bird on the other, on whirling the disc as described, the bird and cage will both be seen; if the turns are over five to the second, persistence of vision will keep both objects in view, so that the bird will be seen in the cage. Other objects can be drawn so as to give all sorts of effects. A man on one side and a horse on the other will give the representation of a man riding. Of course the figures must be drawn right side up, or the rider may be upside down and the bird cage may have its top downwards.

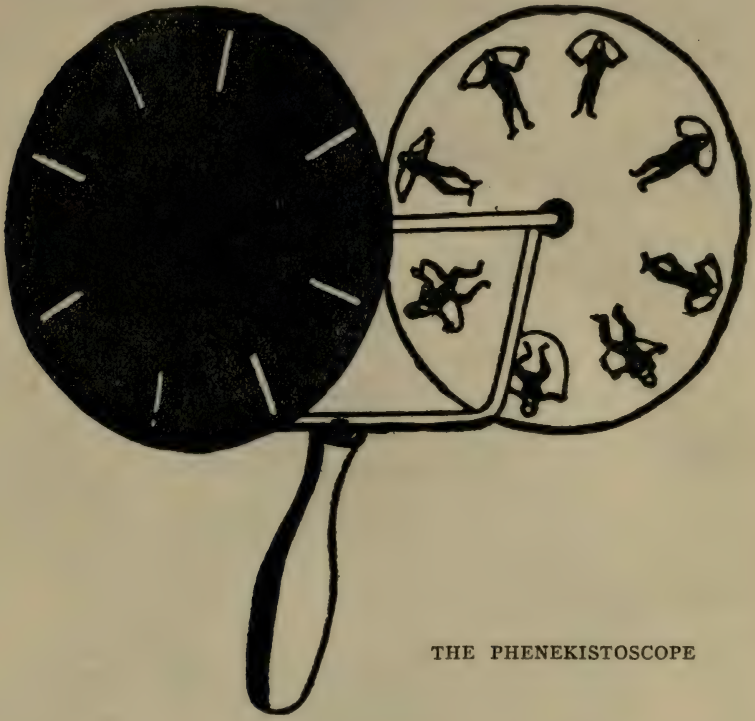


THE THAUMATROPE

This simple toy has been assigned the imposing name of the thaumatrope, the wonder turner. It first appeared about 1826.

The Phenekistoscope

As an advance on this a series of pictures were painted or printed on the surface of a disc of cardboard twelve or fifteen inches in diameter. The pictures were spaced around a circular band as near the edge of the disc as possible, representing the successive positions of a moving object, as of a man walking, or a sawmill cutting wood. This piece of paper was mounted on an axle passing through its center on a handle, and back of it was another piece of heavy paper or cardboard, a couple of inches larger in diameter. A series of radial slits, one for each of the drawn figures, were cut near the circumference of the other disc. The two discs were turned rapidly together. Intermittent vision was afforded through the slits, one picture succeeded the other with less than the fifth of a second between, and the whole set of figures seemed to be in active motion.



THE PHENEKISTOSCOPE

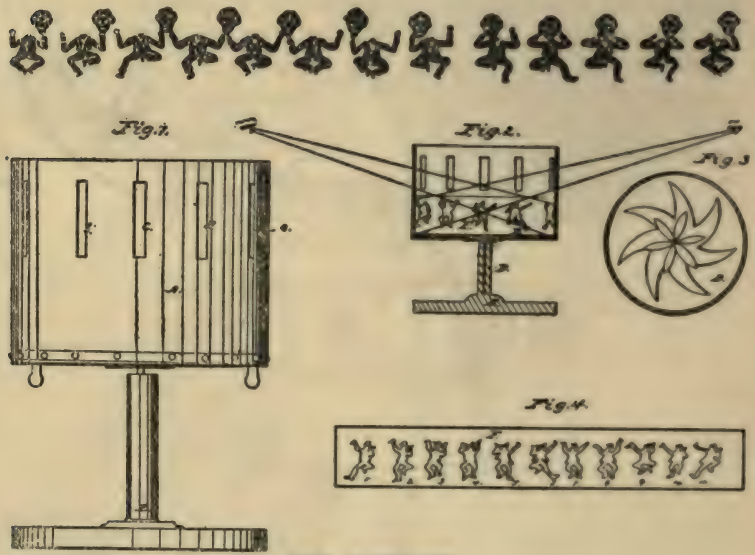
This was an advance on the little disc of the thaumatrope: it received the title of the phenekistoscope. This is pretty near to living pictures.

THE ZOETROPE

The next step was to draw the pictures upon a strip of paper about a yard long and two or three inches wide. A bandbox-like cylinder was mounted so as to be rotated by the hand, its axis being vertical. It had a series of slits around its upper edge, one slit for each figure. The strip with its figures was placed around the bottom of the box inside it, and the box was spun around by hand. The observer looked through the slits. About half the figures were seen directly and by persistence of vision; they were drawn to represent the successive stages of moving objects, and when looked at through the slits, seemed to be in motion.

This was a favorite toy some decades ago.

The fact that the figures were originally drawn by hand, differentiates them from the motion picture work of to-day, in which even the work of the cartoonist and animator is photographed on the film. In old days photography was not used; the figures were engraved and printed on paper.



THE ZOETROPE

The cylindrical box was supposed to rotate so that the slits would succeed each other with less than one-fifth second interval. With each of the toys a set of perhaps a dozen pictures would be supplied. It was called the zoetrope.

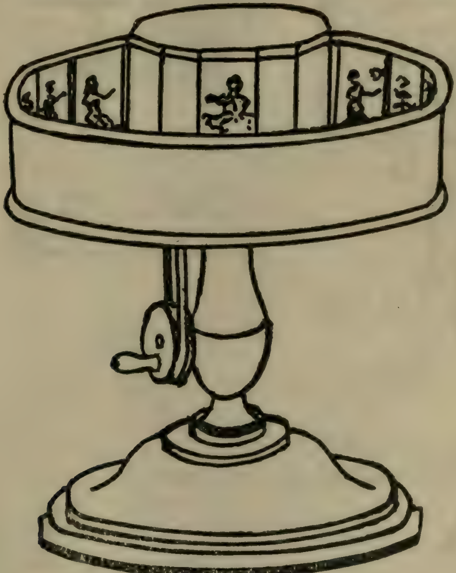
Continuity of Motion in Early Machines

In these early productions of moving pictures one thing is to be noted. The motion of the pictures in the machine was continuous, there was no intermittent motion and rest as in the film projection. It would be a great relief if the intermittent feature of the projection of films could be avoided.

The breaking of films, the wearing of the perforations, the trouble with sprockets and the like are due to the necessity for the change from rapid motion to repose, some sixteen times a second. The problem of doing away with intermittent motion is now being studied. It would be a great advance, and curiously enough, it would be a return to the disc and the cylindrical zoetrope.

The toys just described were not adapted for an audience, although two or three might look through the slits of the cylinder at once. Next the problem of projecting them upon a screen so that they could be seen by a roomful of people arose.

The date of this predecessor of the moving picture of to-day, is put at 1860 in England, where it was patented by an inventor named Desvignes. In 1867 a patent for a similar toy was granted in the United States to William Lincoln of Providence, R. I. The name "zoetrope" is credited to the American inventor. The United States patent is dated April 25, 1867; it is number 64,117.



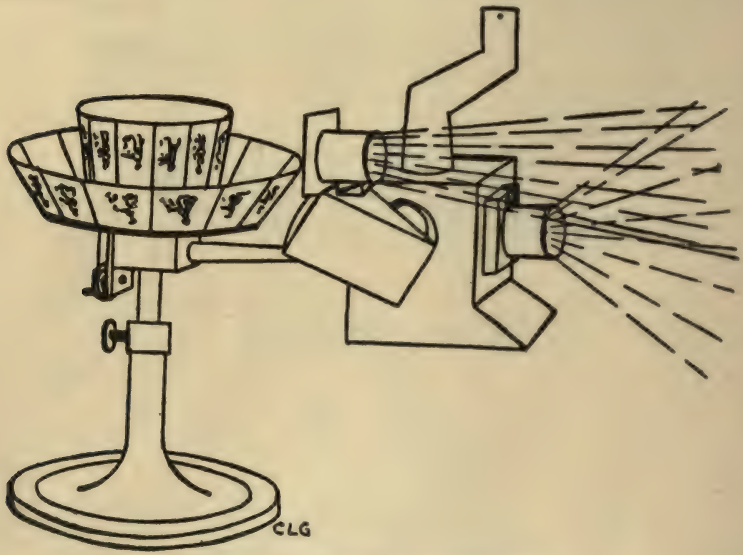
THE PRAXINOSCOPE

THE PRAXINOSCOPE

In the zoetrope the band of paper in the cylinder was looked at directly, and a whole series of figures were seen in motion at once, where, of course, only one should have been in the field of view. So a Frenchman, M. Reynaud, improved at once the name and the action of the machine, placing a set of mirrors in the center to reflect each a single image. As they were flat mirrors, successive reflections were seen, so that there was no need of slits; the observer looked directly into the mirrors and obtained the moving effect. This modification of the zoetrope received the name of the "praxinoscope."

EARLY ATTEMPTS AT PROJECTION

In the Paris journal, *La Nature,* in the year 1862, there was published a description and illustration of a development of the praxinoscope, in which there was carried out a projection of the images on a screen. Two series of pictures could be simul-

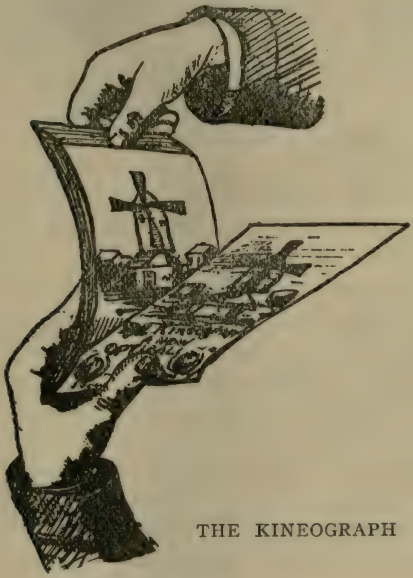


THE PROJECTING PRAXINOSCOPE

taneously projected by two separate lenses. The arrangement did not meet with much success. The pictures were on an endless band, and were projected with considerable loss of light. A later attempt was more complicated, and is also illustrated in the same journal. Like the first attempt at projection of the crudely drawn figures it never had any success apparently, for little is chronicled about it.

THE KINEOGRAPH

Finally there is one thing, which must not be omitted from the category; it is the kineograph of 1868. It was a book, on one side of whose successive leaves there were imprinted figures in successive phases of motion. On letting the leaves turn over rapidly the pictures succeeded each other with such rapidity that quite a good effect was produced, except that the effect lasted but a few seconds, for the book was soon exhausted.



THE KINEOGRAPH

COLEMAN SELLERS' PRODUCTION OF MOTION PICTURES

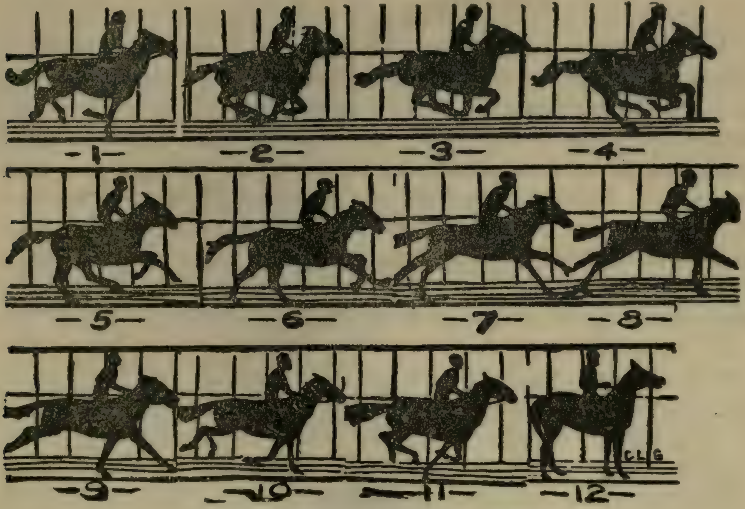
What was almost a modification of the book of drawings or engravings is credited to Coleman Sellers of Philadelphia, Pa., in 1861; this is the year in which a patent was awarded to him for the invention. A series of photographic views of successive phases of a moving figure or figures were exhibited in the old fashioned box stereoscope in rapid succession, and a motion picture effect was produced. Here the pictures could be seen by only one person at a time.

HEYL'S PROJECTION OF MOTION PICTURES

What seems to have been a true exhibition of projected motion pictures was given in February, 1870, at the Academy of Music, Philadelphia, Pa. by Mr. Henry R. Heyl; he called his apparatus the "Phasmatrope." He photographed posed motionless figures of real performers in poses to represent successive phases of motion. These were taken on glass for there were no films in those days. They were mounted in circular fashion and were projected on a screen by a magic lantern in rapid succession. The interesting feature of the arrangement is that a shutter was used to mask the period of change from one picture to another. There were eighteen pictures in each set, and they were changed, as desired, a whole set at a time.

MAREY, MUYBRIDGE, AND LUMIÈRE

The work of Marey, in France, and of Muybridge, in America, hardly touched upon projection, but was practically confined to the taking of instantaneous photographs of animals, men, and birds in motion, so their really fundamental work will be passed by. Lumière, the eminent French photographic investigator, brought out an early improvement on the kineograph, the booklike arrangement of pictures, to which we have alluded. A complete circle of leaves was used, which were turned around like the spokes of a wheel under the gaze of a single observer, whose vision was assisted by a lens. While this was not projection it did give moving pictures. It is to be recorded, however, that Muybridge did make an effort to project some of his instantaneous photographs by an apparatus he called the "zoöpraxiscope." The early investigators of animal motion and of the production of moving pictures seem to have exhausted their ingenuity in the naming of their machines.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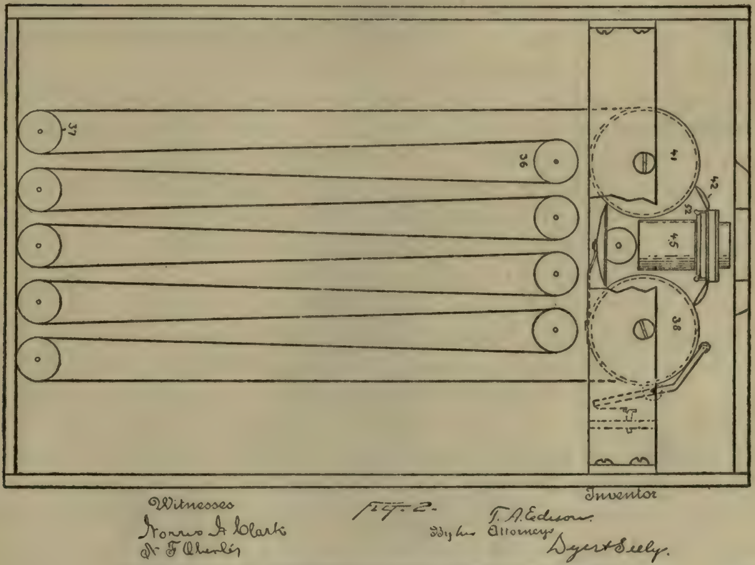
MUYBRIDGE'S RUNNING HORSE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Inventor
Witnesses
Fig. 2.
T. A. Edison
Norris A. Clark
By his Attorneys
W. F. Oberlin
Dyer & Seely.

THE EDISON KINETOSCOPE PATENT DRAWING

THE CELLULOID FILM

At last the celluloid film made its appearance in the photographic field; and to Edison is credited the first use of the long film for motion pictures. This goes back to 1890 and 1893. The photographs were on a long strip of celluloid, exactly as at present, and were exhibited in a closed box, to a single observer at a time This was the kinetoscope, and excited much interest. A long film was fed up and down over a series of rollers, being moved by a motor. The great achievement was the original taking of the pictures, once this difficult operation and problem was disposed of, the projection was comparatively simple.

It is not the desire of the author of this book to give a full history of the development of the invention of the moving picture, whether from the standpoint of the taking of the minute photographs on the film with the requisite mathematical precision, or from the standpoint of projecting them with the magnification of over a hundred times their diameter.

CAMERA AND PROJECTOR

There is one thing to be observed about the whole operation, which thing is, that the two phases are almost exact reverses of each other. In taking the pictures on the film, so as to obtain the long succession of negatives, the film has to have the intermittent motion, which the final and positive film is to have in the projection machine. This intermittent motion must be as accurate as that imparted to the film in the projection machine. Not only is this the case; the motion must be identical in all respects. By practice the photographer acquires the power or faculty of turning the handle of his camera with great regularity. This is an essential factor in the work. For although the speed of production can be changed within wide limits by the operator at the machine, the exposures on the film must be so taken by the photographer that there will be no sudden changes in the rate of action. A man in the pictures must not suddenly change his speed of progression without some cause in the tale the film is telling. If the photographer has used too high or too low a speed all through the length of the film, no great harm is done, because the operator can rectify the trouble by running the projection machine slower or faster, so as to get the proper rate of action of the figures on the screen. But a change within short lengths of the film cannot be successfully rectified in the projection without much trouble if at all. As regards speed the first instruments, the camera in the field or in the studio, should correspond in speed with the speed of the cameras, for such they are, in the projection booths, wherever the film may be shown. This is so true that it is to be regretted that a more exact correspondence than exists at present between the two cannot be obtained.

In the early days of the art it seemed a comparatively simple thing to project the pictures on the film once they had been taken as a string of exposures, developed as negatives, and printed as final photographs. The soul of the whole process inhered in the taking camera, and it still is there. If the taking camera does not do its work the projection machine is helpless. It is curious to see the almost primitive way in which the projection of the pictures was done in the early days. The great thing was to produce a successful film. The success of the film depended on one thing above all others. It was simple to secure the proper lens; the art of making films for the short exposures of the motion picture camera was known; the gist of the problem was to secure the accurate shifting of the film from picture to picture. The shift had to coincide with the closing of the shutter, and every shift had to move the film exactly the same distance, a distance which had to be invariable; a difference of a minute fraction of an inch would throw out the picture, destroying the registry, and, if constant, producing an unendurable flicker. It is, however, fair to say that the audiences of early times stood more defective presentation of pictures than those of the present era will submit to.

THOMAS A. EDISON

In the early days of the motion picture development Thomas A. Edison appears at the very beginning. As far back as 1887 Edison conceived the idea of combining the motion picture and phonograph so as to produce "speaking motion pictures." In the interval of the next two years the successful film was being developed by the Eastman Company. In the authoritative life of Edison, (Dyer and Martin, 1910) the year 1889 is assigned as the date of invention and production of the first motion picture camera of the modern type. All the early experimenters were forgotten, the long film was used, its motion was produced in the intermittent movement of to-day, and the Edison camera, as it is called in the "Life of Edison" is the accepted standard for the taking of motion pictures.

Now let a motion picture camera be taken, and used for projection with a powerful light behind the film to do the work, and the motion picture projection machine is produced. The point to be made is that the work of the two instruments, is so very nearly alike, as far as the mechanism of the process is concerned, that the instrument, which will do the work of the one will do that of the other with comparatively slight modifications. Hence it follows that the invention of the camera, with its wonderful intermittent movement, included and involved the invention of the moving picture projector.

EDISON'S LETTER

The following letter of the great inventor to the *New York Times* tells the story of the invention in Mr. Edison's own words. For further details the reader is referred to the "Life of Edison" already spoken of.

> *"The writer of screen news in your issue of June 5th,* 1921, *does me an injustice in citing a lot of claims tending to deprive me of the honor of being the inventor of the modern motion picture. The injustice arises through a misunderstanding.*
>
> *"The main invention was the Kinetograph, which was an instrument for recording ("taking") motion pictures, as now used. It was not the apparatus for the reproduction of the pictures, enlarged, on the screen. It is on the projecting machine only that the claims of others can be based, as this is the same as the recording instrument with several attachments to adapt it for screen purposes.*
>
> *"At first I put out several hundred reproducing machines, which reproduced the pictures with but little enlargement, and I was starting to make the additions to the recording instrument to adapt it to a greater enlargement for projection on the screen as we now use it, when Mr. Armat presented to my agents a better device for projection than I had at the time. Soon afterwards Lumiere of France used*

my recording instrument, adding another and different kind of device to adapt it for screen enlargement. These reversed recording machines were introduced commercially as Projecting Machines, but the additions and changes were merely detail improvements on my prior and basic invention, namely, the Kinetograph, or Recording Machine, under which I claim to be the inventor of the modern motion picture."

THOMAS A. EDISON,
Orange, N. J., June 8, '21.

To the Editor of The New York Times:

The letter given above is interesting as showing the views of the great inventor as to the relation of the projection machine to the motion picture camera. One is nearly the same as the other, except in some details and in the use of the lamphouse to give the facilities for operating the powerful light needed for the high magnification of the image on the screen. The projection machine consists of two parts or divisions, one is the lamphouse; the other is the head of the machine. In the head is contained the distinctive machinery of the projecting mechanism. Here is the intermittent movement, the sprocket rollers, the reels and all that makes up the real mechanism of the machine. In the head are to be found the representative appliances of the motion picture camera.

It is quite outside of the scope of this book to give the interesting history of the growth of the motion picture art; from its humble beginnings, and later developments, to its present position as one of the great industries of the world, neither is the history of the development of the perfected motion picture machine to be traced through its steps. For the improvements of the present century have been more in accessories than in the machine proper. Its great feature to-day is the skillful manufacture of the machine, for it is now a beautiful piece of machinery; nothing is omitted or forgotten, which will tend to make it better.

CHAPTER II

ELECTRICITY AND MOTION PICTURES

ELECTRICITY plays a leading role in the projection of moving pictures. In the old days of the calcium light and the improved magic lantern, which then received the exalted and incorrect name of the stereopticon, electricity was not used in any way to project the lantern slides. Now all has changed, and electricity is the one essential thing in the work. It produces the light, it regulates the arc that gives out the light, it drives the mechanism of the machine, and does various other minor services, if called upon. The power may be received from the public service lines, and may require modification, and this modification, the change of voltage it may be, or the converting of an alternating current into a direct current, calls for the use of electrical apparatus. The arc light, if such is in use, has to be treated intelligently. A good operator will get much better light out of the lamp than a poor one will. In an advanced installation there will be a quantity of electric machinery requiring constant attention and expert treatment. The general recommendation may very properly be to the effect that if there is anything serious the matter with the electric installation, an expert electrician should be sent for, as it hardly falls to the operator to do extensive work and repairs on the machinery in question. But anyone, who at the present day wishes to take up the career of a motion picture operator, should not regard the life in the projection booth, as the limit of his ambition. He should look forward to becoming a motion picture engineer. He will find that the operation of a motion picture machine, where there is a first class equipment, is a very simple matter on first sight. The electric power seems to do it all for him. But let something happen and then his knowledge of electricity will probably be called on and he will have perhaps to think quickly, while the audience is waiting for the continuation of the exhibition. It is also to be remarked that while the application of electricity has lightened the work of the operator to a very great extent, and while he no longer, in electrically fitted out installations, has to turn the handle of the projection machine with one hand and work at the arc lamp with the other, never ceasing for an hour or more, there is under his charge a lot of fine electrical machinery, which if neglected will suffer permanent injury and the neglect will at least exact repairs.

Electricity and the Operator

It follows that a more extensive knowledge of electricity is required on the part of the projectionist of to-day, than obtained in the case of his predecessor, it may be, of only a few years ago. The present time, too, has seen the creation of a new branch of engineering, the motion picture engineer. Thanks to his efforts the industry is now being put on a scientific basis. So far only electricity has been spoken of. But there is far more than the electric side involved. If the reader of this book will examine the proceedings of the Society of Motion Picture Engineers and papers presented before other societies touching on the industry, he will realize that there is a vast field to be cultivated by one, who desires to really be more than what is called a mere projectionist. The projecting which used to be everything is now the least part of the work. The science of optics, the laws of the radiation of light and of illumination, the principals of optical projection, involve an endless amount of study. Over and over again in print incorrect views and statements on the optical aspects of the science are to be found. The true engineer will by going to original sources study up the science of the art for himself, and will not be led astray by incomplete presentation of the laws affecting the operation of the projection lens or objective. All this is said in no spirit of criticism. It is felt that this book will fall into the hands of many of the younger aspirants for places in the great motion picture industry. The author's advice to such is in line with what has been said here. There is an immense area of ground to be covered, if the student desires to become more than a projectionist, and wishes to graduate as an engineer. He must learn the mechanism of the projection machine. At first sight the mess of wheel-work in the projection-head of the machine may frighten him, but a little study will show him that there is little complication, and that the apparent difficulty of comprehending it all is sure to vanish after a few days acquaintance. He may feel that the arc lamp in the lamphouse, with its various adjustment handles, is a little beyond him. But all these troubles will soon vanish. The machine head is necessarily crowded with machinery because it must be compact. Its object is to feed in a definite way a thin narrow strip of celluloid down through the gate. The movement of the film has to be in general terms as accurate as the movement of the works of a clock. The head of a projection machine includes the most carefully constructed machinery, far superior in class to that of the majority of clocks. But there is no complication about it. It seems intricate because it is so compact.

The Arc Lamp

The arc lamp, now in such general use, is simplicity itself. There are but a few adjustments, some for the carbons, some for the lamp proper and some for the lamphouse and the lamp together. But it is all so well worked out and so generally standardized, that there will be not the least difficulty in learning the manipulation. But after the practical part, summarized thus, has been learned, the real study will begin. Not many years ago there was a great difference in the construction of the projection machines. Some had one kind of shutter and some had another, and even the location of the shutter varied, for in many of the old time machines the shutter was placed behind the projection system and back of the film. There were many types of intermittent movement; now there are comparatively few.

Mechanical Aspects of Projection

It follows, that, as far as the mechanical apparatus is concerned, the path of the beginner is made easy for him. The great manufacturers of motion picture machines have the best engineers at their command, each company is ambitious to do better than its competitors, and nothing is spared to secure the best of material and highest mechanical skill to be used in the production of the mechanisms. All this is in the direction of helping the operator; the factory is working for his benefit directly, for the machines now produced are so good and so well designed, that they can almost be said to run themselves. At least when all is going well the interior of the projection room is far from being a busy place. Everything, except the minor adjustments, is done automatically.

AUTOMATIC FEATURES.

This automatic feature on its face would seem to simplify the work of the operator. This it does while all is operating well, but it is in emergencies, that the capabilities of the operator will be called on, and in the adjustments and general operations to be done when the machine is not in operation. A multiplicity of appliances, electric for the most part, are to be taken care of; the projection system is to be looked after; the lenses are to be periodically cleaned, and a lens succumbs more rapidly to bad cleaning than to total neglect. Special cases arise, so-called keystone effect to be coped with, the location of the apparatus in the case of the fitting-up of a new hall, the proper number of foot-candles required in each individual case, and the determination of the focal length of the objective lens for its work in the hall in which it is to be used; such are illustrations of questions and problems, which have to be worked out by engineers, and it is for such propositions as these that the operator must endeavor to prepare himself, for if he ever graduates from the projection booth, they or their like will be given to him to answer or to solve.

ELEMENTARY NOTIONS OF ELECTRICITY

Everyone is familiar with an electric battery. It consists of two plates called electrodes, which are contained in a jar, and are immersed in fluid called the electrolyte. One of the plates is of zinc, and this is universal for no substitute for zinc has ever been found. It will be understood that this applies to the primary battery only. The other electrode is a plate of carbon or of copper, although various other materials have been used for this part. Now it is pretty nearly a universal practice to employ one or the other of these two. When the two plates, zinc and carbon or copper, are immersed in a solution, which acts upon the zinc chemically and tends to dissolve it, the conditions are established for the production of an electric current. If a wire or other conductor is caused to connect the two plates or electrodes a current of electricity will flow through the wire and through the electrolyte also. The current goes around in a sort of ring, through the wire and through the solution, which is its circuit. In the battery one of the plates only is attacked and dissolved by the electrolyte. This plate figures as the source of the energy developed, and is given the very obvious name of the positive plate. It is easy to remember this, because the plate, which does not dissolve is certainly negative in the general sense of the word; it is doing nothing in the way of chemical action.

In the so-called dry battery there is an electrolyte, which is mixed with a solid substance to prevent it from splashing about, but the dry battery is a wet battery in reality, for its action depends on the liquid electrolyte, which is mixed with the dry absorbent. In the dry battery the jar is made of zinc, and acts at once as the container and as the positive plate. The wet battery was the original combination, and for many years was the only way of producing an electric current.

Direction of Flow of an Electric Current

It is necessary to assign a direction of flow to an electric current; we know little about its real nature, but it is assumed to be of the nature of a current, perhaps of a flow of electrons. The current is assumed to go from the carbon or copper electrode of the battery through the wire to the zinc electrode. Here the memory may be helped by the fact that the letter, C, comes befor the letter, Z, in the alphabet; the current is naturally taken as starting from the plate, carbon or copper, whose initial comes earlier in the alphabet than Z for zinc. It is not to be supposed that this fact of the precedence of letters had anything to do with the assignment of direction to the current; it gives a convenient way of remembering the direction of the flow of electricity.

The Electric Current

Many beginners have had much trouble in understanding the idea of what a current is. It is not the expression of a quantity of electricity, but of the rate of flow of the same. A unit current is one, which passes a unit quantity of electricity in a unit of time. The practical and everyday unit of quantity of electricity is the coulomb. This is the quantity, which if caused to deposit silver from its salt in solution, will deposit .001118 gram of the metal from a 15% solution of silver nitrate. It may take a long or a short time to do this, but when that amount of silver has been deposited, we know that one coulomb has passed through the solution of the silver salt. Now the conception of the electric current can be formed. We have seen what the practical unit of electric quantity is, and we know that the second is the unit of time. A current going through a conductor, such as a wire, is taken to be the passage of electricity through the wire, just as water passes through a pipe. If a current passing through the silver solution took one second to precipitate the .001118 gram of silver, it would show that one coulomb had passed through the silver solution in the second. A current is measured by the quantity of electricity it passes in a second, just as a current of water could be measured by the gallons passed in a second. A current of electricity passing one coulomb of electricity in a second is a current of one ampere.

RATE UNITS

It follows that the statement of the strength of a current tells us nothing about how much electricity it is delivering in coulombs or in any other unit of quantity; it merely tells that the current is delivering as many coulombs in a second as there are amperes in the current. The ampere is a rate unit only, and the current is measured in rate units. If the power of a steam engine is stated to be one horse power, that does not tell what work it will do, unless the time, during which it is to work is also specified. Any motor of one horse power can raise 550 pounds one foot in a second, but if such a motor is working, no one knows how many pounds it will raise a foot or how many feet it will raise a pound or more, unless the time it is going to work is also known. The horse-power is a rate unit, and no absolute quantity is specified by it, unless the time of its action is also specified. The same is the case with the ampere.

ELECTROMOTIVE FORCE

Water in a pond or in a level trough does not flow; there is no current. Air will not flow through a pipe unless pressure is applied. A current of electricity will not flow through a conductor unless electrical pressure is applied. This pressure is called electromotive force often written E.M.F. or e.m.f. as an abbreviation. If electricity is acted on by e.m.f. a current will be produced through a conductor by the e.m.f. in question. We have seen that there is a practical unit of current, called the ampere. The practical unit of electromotive force is the volt. In an analogous way the unit of pressure of water might be called the pound to the square inch, or a hydraulic head or elevation of a foot. The ampere has been seen to be a unit of rate, a rate unit. The volt is not this; it is simply a unit of amount of electric pressure as it is often called. As the word electricity itself is hardly definable with exactness, it is not easy to define the volt; it is almost fair to say that electromotive force had best be accepted as the expression of a phenomenon not yet to be explained satisfactorily to the reader. Its analogy with the pressure of air causing a flow of air through a pipe, or with that of water or steam in pipes is sufficient to present its action to our minds.

Resistance and Conductors

We now come to resistance. This is the third great factor on which all ordinary electric calculations are based. We have seen that if a quantity of electricity is acted on by electromotive force, a current will be produced. But this current requires a path to traverse, and in what was said about the action of e.m.f. on electricity, it was taken for granted that such a path existed; without this assumption the statement would not be accurate. The path, through which electromotive force can drive a current is a circuit or it may be a portion of one. This is said because electromotive force is not to be thought of as a sort of end force pushing a current from one end of a conductor through its length; it must be thought of as present in all parts of the circuit, its total amount divided in proportion to the different portions of the circuit, which are being considered. All this will come out clearly a little later. But in the case of a current in a circuit the e.m.f. must be thought of as permeating the whole line, so that no part of the circuit is without it.

An electric circuit is usually composed of a wire of copper or iron or recently of aluminum. Every metal which conducts electric quantity in a current is called a conductor, and as some conduct better than others, copper better than iron of the same dimensions, and a large wire better than a small one of the same length, conductors are said to vary in resistance. It would be better if they were said to vary in conductance, as they are primarily conductors, but all ordinary electric calculations use the quality of resistance in determining the actions of currents in circuits.

The practical unit of current we have just defined. The practical unit of electromotive force is the pressure, which can force a current of one ampere through a conductor of a resistance of one practical unit. The practical unit of electromotive force is the volt; the practical unit of resistance is the ohm.

Practical Examples of Value of Units

The great trouble some students encounter in grasping the idea of these units is that they seem abstract. But they are far from that. A coulomb decomposes many chemical compounds, always in exact proportion and in exact chemical relations. A current passing through a conductor heats it, and expends heat upon it in exact relation to its own strength. All forms of the electric light are due to the action of the electric current on a conductor. To measure a current we need not procure an electric meter; it is enough to weigh the amount of some metal, which it will deposit from a solution in a given time. From this we get the number of coulombs, and the number of coulombs divided by the number of seconds it took to deposit the metal corresponding to the coulombs, gives the amperes of the current. Next we must find some good standard of resistance to make it less abstract. A column of mercury 1 sq. mm. cross-section and 106.3 cm. long has one ohm resistance. Nothing can, however, be done for the volt. We must be content to take it as the pressure, which will force a current of one ampere through a conductor of one ohm resistance.

Ohm's Law

The law governing the flow of current in an electric circuit is known as *Ohm's Law,* and may be defined as follows:—*the strength of the continuous current in any circuit is directly proportional to the electromotive force in the circuit, and inversely proportional to the resistance of the circuit;* that is,

$I = \frac{E}{R}$, from which $R = \frac{E}{I}$, and $E = IR$, where I = current in amperes, E = E.M.F. in volts, and R = resistance in Ohms.

POWER

A conception of power comes next. This is a precise quality, of as exact scientific status as electric current or resistance. It is not a mere expression of capability, when it is used in mechanics, but is a quality of definite specification. It is a rate unit, and expresses the rate at which energy is exerted, or if a more popular form of expression is to be used, it is the rate, at which work is being done. Energy is expended in raising a weight from the ground to a height, or from one height to another. Suppose the weight is a pound and it is raised to a height of one foot; then one foot-pound of energy has been expended. The number of foot-pounds expended in a second gives a measurement of the power exerted. While foot-pounds have been used here as a unit of energy, there are many other units. The essential thing to understand is that power is a rate unit, so that if we know that a certain machine is working at a rate of so many power units, that alone does not tell anything about how much it has done, unless the time is known, during which it has exerted the stated power. The case is comparable to that of the ampere in the relation of the power unit to the time it operated.

POWER UNIT A COMPOUND UNIT

In the exertion of electric power two units are concerned; one is the current, the other is the potential. If there were a conductor of no resistance an infinitely strong current would be maintainable through it with an infinitely low voltage. If there were a conductor ot some resistance for the current to pass through, a certain number of volts would be required to force the current through the resistance in question. It is not necessary to go into the matter further than to say, that the power is equal to the product of the two units concerned in its production; it is equal to the potential multiplied by the current, or to the volts multiplied by the amperes. The unit of electric power in the practical series is the volt-ampere or watt; the latter is the name of the compound unit, which, however, is often called the volt-ampere. It is expressed in algebraic symbols as I E, where I is the current and E is the potential producing the current. By applying the values of I and of E deducible from Ohm's law, we obtain, for the same volt-ampere, the expressions, $\frac{E^2}{R}$, and I^2R, both identical in value. To satisfy himself of this let the reader take any value for amperes and for volts, and multiply the two; the product will give the watts of power, if the volts named are expended on maintaining the amperes of current. Now let the reader introduce the same values in the alternative formulas given above, and he will find that the other formulas will give the same value for the watts.

Expressions for Power in Electric Circuits

Suppose that a current of five amperes is forced through a conductor by a potential difference of nine volts. The watts would be equal to the product of amperes by volts, or $5 \times 9 = 45$ watts. In such a circuit, by Ohm's law, the resistance would be equal to the quotient of volts divided by amperes, or of 9/5 ohms Substituting this value for R, in the two alternative formulas given above, we have for the power, $\frac{81}{9/5}$, which is equal to 45, and for the other expression, $25 \times 9/5$, which is also equal to 45. Thus the same result is given whatever formula is used, which is as it should be. The formulas, I E, and I^2R, are the ones most used; if the volts and resistance are known the formula, $\frac{E^2}{R}$, may be used, to obtain the watts without applying Ohm's law.

The Horse-Power

The horse-power unit of power is equal to 550 pounds raised one foot in a second. If any number of pounds are raised any number of feet in one second, the product of pounds by the feet raised, when divided by 550, gives the horse-power. This is pure mechanics. By experiment it has been found that 746 watts are equal to one horse-power. Thus 746 amperes actuated by one volt, if there were no loss of power, would be able to raise 550 pounds to a height of one foot each second that the amperes and volts operated. Or they might raise one pound 550 feet each second, or two pounds 275 feet each second, and so on. If an arc lamp takes 35 amperes at 65 volts, the watts absorbed by it are equal to $35 \times 65 = 2275$ watts; dividing this figure by 746 we have a little over three horse-power expended in operating the arc light.

Simple as these calculations are, there are many to whom they are quite unknown. If the reader will learn Ohm's law perfectly, and apply it to the evolving of power values by the three formulas given, it will be a most valuable practice. There is nothing more unsatisfactory than working with definite quantities, day after day, when their meanings and relations are not understood.

General Statement of Electric Factors

An electric current is conducted along or through a number of substances known as conductors. Prominent among these are the metals. They differ greatly among themselves, some conducting electricity much better than others. Nothing conducts electricity perfectly, the relative difficulty, with which different substances conduct it is called their resistance.

Resistance has to be expressed in words, has to be used in numerical calculations, therefore there must be a unit quantity, just as there is a unit of length, the foot or the mile, and of weight, the grain or the pound, and so on. The unit of electrical resistance is the ohm.

It is named from a very distinguished electrical investigator. Most of the electrical units are named from scientists also; such are volts, amperes, coulombs, and many others.

An electric current decomposes various compounds, produces heat and has various other effects. These effects are greater or less according to whether more or less electricity is used in producing them. Therefore we must have a unit for a quantity of electricity. The unit of quantity of electricity is the coulomb.

The electric current is the flow of coulombs of electricity through a conductor. It must have a unit. The unit of electric current is a quantity of one coulomb a second; it is called the ampere.

To cause a current of electricity to pass through a conductor some force is needed, because every conductor has resistance. The force required to overcome this resistance is called electromotive force, often written E.M.F. or e.m.f. This force varies in amount and must also have a unit to express its quantity by; the unit of electromotive force is the volt.

The ohm, ampere, and volt are the units most familiar in everyday operations. The coulomb is not often used in calculations, because the great majority of electric engineering work is done with current electricity, and the other three units are perpetually used and called upon in specifications and the like.

Ohm's Law is this: The intensity of a current in a conductor is equal to the electromotive force divided by the resistance. This implies the use of corresponding units. It may be put more generally to the effect, that the current varies directly as the electromotive force and inversely as the resistance.

OHM'S LAW IN PRACTICAL UNITS

An e.m.f. of one volt will force a current of one ampere through a resistance of one ohm.

This is the famous Ohm's Law, expressed in practical units, and anyone who has to deal with electricity should know it perfectly. It can be put in other ways.

If a current of one ampere passes through a resistance of one ohm, the e.m.f. must be one volt. If a current of one ampere is produced by one volt the resistance of the conductor through which it passes must be one ohm.

If the e.m.f. is doubled the current will be doubled; if the resistance is doubled the current will be halved and so on. The relations are contained in the formula of Ohm's Law:

$$I = \frac{E}{R}$$

in which I indicates the strength of current (generally amperes), E, electromotive force, (generally volts), and R, resistance (generally ohms). If one of these units is employed in a formula or calculation, the others must be used if occasion arises; units must be correctly used.

In the formula given above there is a horizontal dash; the meaning of this dash is not always understood. You will be told that it indicates a fraction. This is a very limited description; it is a sign of division, and means that the upper figure or quantity is to be divided by the lower one.

A Fraction a Sign of Division

The only reason that it denotes a fraction is because a fraction is the division of one quantity by another. Or it may be put that a fraction is the expression of such a division to be done. If one-half is to be more fully expressed, it may be called one divided by two; three-quarters is properly three divided by four, and so for all fractions.

Dividing Small Numbers by Large Ones

Elementary arithmetic is not within the plan of this book, but here as light confusion may exist for some, when it is proposed to divide a small number by a large one. This is done by the law of decimals. Suppose the division $\frac{1}{2}$, is to be performed. Put the one, 1, down with a period after it and at least one cipher to the right of the period. Then to the left write the two, 2, as the divisor, and proceed as in ordinary division. This will be short division.

$$\begin{array}{r} 2)\ 1.0 \\ \hline \cdot 5 \end{array}$$

Suppose the fraction was one divided by three, $\frac{1}{3}$. This time more ciphers will be needed. Annex three ciphers to the one, 1.

$$\begin{array}{r} 3)\ 1.000 \\ \hline \cdot 333+ \end{array}$$

The result or answer of the first division reads five one-hundredths; the answer of the second, three hundred and thirty-three one-thousandths plus. The plus means that there is a remainder. The remainder could have been made as small as desired by annexing more ciphers, and going on with the division until they were used up.

DECIMALS IN DIVISION

Long division is done in the same general way. If there are decimals in the divisor, the number which is divided into the other, the number of decimals in the answer, the quotient, has to be settled. As many ciphers as desired are annexed to the dividend, the division is done in the regular way, until all the ciphers have been taken down, and the decimals in the divisor are counted and their number is subtracted from the number counted in the dividend; this gives the number in the answer or quotient.

Take the numbers 3.57 and 4.9 and divide the first by the second. We will annex five ciphers to the dividend.

4.9)3.5700000 (.728571
3.43

The operation is only started; it can be done at length on a piece of paper. The point is to know how many decimals there are in the answer. To find this make the subtraction of one (the number of decimals in the divisor) from seven (the number of decimals in the dividend); this gives six; therefore there are six decimals in the quotient or answer. A period is placed in front of the first figure, so that there shall be six decimals in it, thus: .728571. Often, to make it perfectly clear, a cipher is placed in front of the decimal, thus: 0.728571.

If the reader is not familiar with this work, he should practise it, using an arithmetic, as such operations come into the application of Ohm's Law.

DIVISION IN OHM'S LAW

It will be seen that any number can be divided by any other, and the reason for emphasizing this fact is that in applying Ohm's law, a small number has often to be divided by a larger one, and the result must be carried out, giving as has been seen a decimal fraction. The quantity may be expressed as a vulgar fraction, but it must be realized that a vulgar fraction is only the indication of an operation, and that the operation is not done until the indicated division has been carried out.

In the formula of Ohm's Law, $I = \frac{E}{R}$, I indicates current strength; for all ordinary purposes and in all ordinary calculations, the current is measured in amperes. I therefore means amperes, E means volts, and R means ohms.

UTILITY OF FORMULAS

Many people do not like formulas. There is no more trouble in understanding and applying this formula than in spelling the titles of the units involved. A few examples of all that it tells will now follow.

PRACTICAL EXAMPLES OF OHM'S LAW

Let an electromotive force of 9 volts act upon a resistance of 3 ohms; what will the current be?

Put the volts in place of E in the formula, put the ohms in place of R in the formula, and we have:

$$I = \frac{9}{3} = 3,$$

and as I is expressible in amperes, and must be where volts and ohms are used, the value of the current is three amperes.

Such a current in every second passes three coulombs of electricity.

The fact is to be kept in mind that the fraction is only a short and compact way of telling us to divide the upper number by the lower, and the formula will be seen to be simplicity itself.

Now suppose the voltage, which is the expression often used for the e.m.f., is 3, and the resistance is 9, calculate the current.

Substituting, we have:

$$I = \frac{3}{9} = .333+ \text{ ampere.}$$

The plus sign, +, indicates that there is a remainder, and that the result is only approximate. It can in such cases as this be carried out to any number of decimals; the more places the more accurate will it be.

OTHER FORMS OF OHM'S LAW

Ohm's Law can be put into another shape, where the current and resistance are known, and the volts are to be calculated. This second form is:

$$E = RI.$$

or volts are equal to the product of the resistance of the conductor by the current, which such voltage can produce in it.

If in a conductor of ten ohms resistance a current of six amperes is produced, what is the voltage between the ends of the conductor?

Substituting, we have:

$$E = 10 \times 6 = 60 \text{ volts.}$$

The third form of Ohm's Law is:

$$R = \frac{E}{I}.$$

This is for use where the volts and amperes are known, and the ohms are to be calculated.

If the voltage in a circuit is fifteen and the current is three amperes, what is the resistance of the circuit?

Substituting we have:

$$R = \frac{15}{3} = 5 \text{ ohms.}$$

Now let the three symbols, I, E, and R, be put in a triangle like this:

$$\frac{E}{I \quad R}$$

and we have Ohm's Law in all three forms. Take out any one of the letters and what is left will give the value of the letter withdrawn. Take out E and I R are left. But we have seen that I R gives the value of E. Take out I, and its value is given by what is left, $\frac{E}{R}$, as in the first form of Ohm's Law given above. Finally if R is taken out, $\frac{E}{I}$, is left, the third of the forms of Ohm's Law.

If the reader will do a few examples by the first set of formulas and then will apply the triangle, as it may be called, it will be seen how simple Ohm's Law is.

ELECTRIC ENERGY

If a conductor had no resistance a current would pass through it without the expenditure of any electromotive force. The conductor would not be heated by the current or affected in any way. But a conductor always has resistance and a current passing through it produces heat and expends energy.

Electric energy is measured by the unit of quantity multiplied by the unit of e.m.f. It is what is called a compound unit—the volt-coulomb. But the unit of energy is of little practical interest in the field of electric lighting, what is wanted is a unit of electric power. Power is rate of energy.

ELECTRIC POWER

A rate of energy of one volt-coulomb per second is the volt-ampere. This is because the ampere is a flow of one coulomb per second. The volt-ampere is called the watt.

THE HORSE-POWER

Electric power for lighting and other purposes is bought by the watt-hour. As there are 3,600 seconds in an hour, a watt-hour is equal to 3,600 volt-coulombs. We first get away from the coulomb, and now get back to it. Yet few ever realize that this is the case.

It would be very troublesome to render bills for electric light in so small a unit as the watt-hour. One thousand watt-hours is the accepted unit. It is called the kilowatt-hour. Kilo is from the Greek and means one thousand.

Everyone has some idea of what a horse-power is. Horses like men differ in power. The mechanical unit of horse-power is supposed to be based on an average horse's power. But that is not of the least interest. A horsepower, as far as the engineer is concerned, is the power, which can raise 550 pounds one foot per second.

746 watts in one second can raise this amount the one foot, so an electrical horse-power is equal to 746 watts. Thus a kilowatt is almost exactly one and one-third electric horse-power.

Generally electric power is sold by the kilowatt. If the projection lamp is supplied from the public mains, the kilowatts used is found by multiplying the amperes passing through the lamp by the voltage of the system, and dividing by 1,000.

POWER AND RESISTANCE

All conductors have resistance. Power has to be expended to overcome this resistance; the electrical power thus expended is converted into mechanical power as a rule. One form of mechanical power is heat, and heat produces light. Were it not for the resistance of the lamp, it would produce no illumination. It would be cheaper to run a lamp of no resistance, but it would give no light. The very thing which uses up expensive electric power, namely, resistance, is what makes the lamps do their work; is what enables us to project the pictures on the screen.

TEMPORARY RESISTANCE

As a general rule the resistance of conductors increases as they get hotter. A copper wire is of higher resistance when hot, than when cold. The same applies to iron wire and is an important factor in the operation of the iron wire rheostat. The hotter such a rheostat becomes the higher is its resistance. This principle operates to make it keep a current approximately constant. The instant the current begins to increase over the amount for which the rheostat is set, the resistance increases and it cuts down the current. If on the other hand the current tends to fall in intensity, the rheostat cools, the resistance of the cooler rheostat falls also, and permits more current to pass.

In this way this action acts like a flywheel of an engine. tending to keep a constant action of the current, as long as the voltage is not changed too much, and to a considerable extent it takes care of small variations in this factor.

RESISTANCE AND THICKNESS OF CONDUCTORS

The resistance of a wire is less as its sectional area is larger. That is to say a large wire has less resistance for a definite length than a small one possesses. A hundred feet of wire half an inch thick would have four times the resistance of one an inch thick. The ratio of the cross-sectional area of circles is that of the square of their diameters. A wire twice as thick as another has one-fourth the resistance. This is expressed by saying that the resistance of wires varies inversely as the square of their diameters.

Suppose we have two wires; one is .25 inch and the other .35 inch in diameter. The question is what are their relative resistance? They vary as $(.35)^2$ is to $(.25)^2$. This is as .1225 is to .0625; the small wire has $\frac{1225}{625} = 1.96$, or nearly twice the resistance of the large one. In performing this calculation be careful to keep the ratio an inverse one. The smaller the wire the greater is its resistance.

RESISTANCE IN SERIES

When wire or other conductors are in series with each other, the resistance of the whole number thus connected is the sum of their individual resistances. If three coils of wire, as in a rheostat, are respectively of 4, 6, and 10 ohms resistance, if connected in series one after the other, will have a resistance of 20 ohms. This is the sum of their resistances taken singly.

RESISTANCE IN PARALLEL

Now let them be connected in parallel. The resistance will be equal to the reciprocal of the sum of their reciprocals. The reciprocal of a quantity is the quotient of one divided by the quantity. The easiest way to carry out this rule and to remember it is in the case of a fractional quantity to invert it, and write the numerator for the denominator and vice versa. For a whole number simply make it the denominator of a fraction with I for the numerator. If it is a mixed number reduce it to a fraction and invert.

Thus the reciprocal of 23 is 1/23; the reciprocal of 3/7 is 7/3; the reciprocal of 3 5/6 is 6/23 because 3 5/6 is equal to 23/6.

Now suppose in our rheostat that the three wires are placed in parallel with each other. The sum of their reciprocals is expressed as $1/4 + 1/6 + 1/10$; the sum of these quantities by the regular rule for adding fractions is 124/240; the reciprocal of this is 240/124 or 1.93 ohms.

A simpler way of arriving at the same result is to multiply the resistances of two of the resistances together and divide by the sum of the two resistances. This gives the combined resistance of the two in parallel. Then with this quantity and the resistance of the third coil repeat the operation. This can be carried out to any number of resistance coils in parallel.

Take the same three resistances in parallel. Carrying out the operation with 4 and 6 we have as the fraction expressing the resistance of the two in parallel, 24/10. The next resistance is 10. The same operation is to be carried out. The product of 24/10 by 10 is 24. This is the numerator of the fraction. The sum of 24/10 and 10 is 124/10. This is the denominator of the fraction, and the resistance is $\frac{24}{124/10}$, or $240/124 = 1.93$ as before. There is no simpler way of doing it than the two ways given here.

Action of Rheostat Coils

It is clear that two coils in a rheostat can be made to give four resistances. Each coil singly will give its own resistance. Two in parallel will give the combined resistance as just explained. The two in series will give the sum of the resistances of the two. This gives a capability of giving four resistances with two coils; it is all a matter of how they are connected.

Practice in Fractions

Practice fractions in addition and multiplication and there will be no trouble in calculating resistances of parallel conductors by the first method given. For two conductors or resistances, for here each means the same thing, the second method is excellent; for more than two the first method is to be preferred.

In the case of parallel circuits each one of the same resistance as the others, the calculation is simple. The resistance of a single resistance is to be divided by the number of resistances in parallel. Twenty lamps of 450 ohms resistance each will when connected in parallel have a resistance of $450/20 = 22.5$ ohms.

Thus if there are two arc lamps to be operated in parallel with each other the combined resistance is one-half that of a single lamp if they are run at equal resistance.

All this class of calculation would be simplified if electricians worked by conductance instead of by resistance. This should have been done from the beginning, it is too late to change now.

CIRCULAR MILS

There is a unit of area much used in electrical work, the circular mil. A mil is the one-thousandth part of an inch. The circular mil is the area of a circle of one mil diameter. If a wire is one-tenth inch in diameter it is one hundred mils in diameter and its area is ten thousand circular mils. The area of the cross-section of a circular conductor is equal to the square of its diameter in mils, taking circular mils as the answer. Thus:

A wire one-thousandth inch, which is one mil, in diameter has a cross section of one circular mil; a wire of two-thousandths of an inch has one of four circular mils; one of three-thousandths of an inch has one of nine circular mils.

CONSTANT POTENTIAL SYSTEM OF SUPPLY

If the poles or terminals of an electric battery or dynamo are connected by a wire a current will pass if the battery is alive or if the dynamo is active. Next let the wire be cut and a lamp be connected to the line, one terminal of the lamp to one end and the other to the other end. The current will go through the lamp and will cause it to give light if enough current passes.

If the lamp is an incandescent one the object of the manager will be to maintain a constant potential difference at the terminals of the lamp. This is the way an incandescent lamp should be supplied.

Suppose it is a 110 volt 25 watt lamp. As a watt is equal to the product of volt by ampere, if we divide the 25 watts by the 110 volts, we shall have the amperage of the lamp; $25/110 = .227$ ampere. Now, in the case before us, there are two ways of running the circuit. The lamp may have its terminals kept at constant potential, which is the regular way of operating incandescent lamps, or a uniform current of .227 ampere may be kept passing through the circuit.

If the reader understands his Ohm's Law, and it is his duty to understand it, he will see that whichever course is adopted, the result is exactly the same. To maintain the fixed current through the single lamp, the generation of the current may be so conducted that an ammeter at the works will be made to read the fixed current of .227 ampere. Or a voltmeter connected from one lamp terminal to the other may be made to read the unvarying voltage of 110. If the amperage is kept constant, the voltage will be constant also and vice versa. It is only one and the same thing based on two different ways of measurement.

INCANDESCENT LAMPS IN SERIES

Next let a number of incandescent lamps, each of exactly this rating, be connected, one after the other on the line, the line being cut to permit the several lamps to be connected. The lamps would then be connected in series.

To supply each lamp the same current would be required, so it would be necessary to maintain the same current as for the single lamp. But the voltage would have to be increased by the addition of 110 volts for each lamp. Incandescent lamps are never connected in series with rare exceptions.

ARC LAMPS IN SERIES

The conditions of a series connection, which this is, are the forcing an unvarying current through the line and lamps, and it is the typical system for arc lamp circuits. Their resistance falls as their temperature rises, so that unless the current were kept constant by some means outside of the action of their resistance, the resistance of the circuit would fall and the current would increase until the lamps were burnt out or until the fuses blew.

The usual system of operating arc lamps in number is to connect them in series on a line through which a constant current is passed.

In series connection if one lamp is extinguished the whole circuit is opened and all the lamps go out. It is evidently not adapted for house supply, although there are contrivances to overcome this trouble.

INCANDESCENT LAMPS IN PARALLEL

Next let the leads or wires from our electric power and lighting station be carried on two parallel lines, with no connection at their extreme ends; no current will pass. Now let a number of incandescent lamps be connected across from one wire to the other, like the rungs of a ladder. To supply such a system it is necessary to keep an unchanging potential difference between the two sides of the circuit. It is no matter whether one lamp or all of the set is burning; all that the station operative has to think of is potential. This he watches by a voltmeter, the amperage takes care of itself. The amperage is twice as great for two lamps as for one and so on; it varies in proportion to the number of lamps burning. But the voltage changes very little. It has perhaps to be increased a little as more lamps are lighted, which slight increase depends for its amount on the resistance of the line.

In laying out the system the engineers had to determine the size of the wire of the circuit by a capacity table, making the wire large enough to carry the current for all the lamps. If the line was a long one it would probably be tapered or reduced in size from place to place as fewer lamps were left to be supplied.

This is parallel or multiple arc connection. It is the system used for incandescent lamps; in it any of the lamps can be extinguished without affecting the others. If there are a hundred or more lamps on the circuit, all except one may be turned out without affecting the solitary one left burning.

CONSTANT POTENTIAL CIRCUITS

The system is also termed the constant potential system.

The constant potential system in some form is the one in universal use for house supply. Where a projection apparatus is supplied from the public service circuit, it will be from a constant potential circuit. In almost all cases the potential difference will be about 110 volts. The voltage will be a little higher near the station, than in remote districts. It will be unvarying at each place.

THE PROJECTION LAMP

The projection lamp will need a constant current, but will be connected on a constant potential circuit. This is on its face wrong and the difficulty is met by placing a rheostat or other appliance in series with the lamp, to secure for it a constant current. The way to get rid of all trouble would be to connect by special line to the station, and to arrange to have a constant current supplied. This is not only impractical, but it would have a serious objection. The lamp may be called upon to supply more light at one time than at another, according to the density of the image on the film, and this change is effected by increase or decrease of current.

Thus an operator may have to call upon his lamp to give more light on some such occasion when the exigencies of the screen may require such changes, or the film may vary in transparency, which will involve the same necessity of regulating the intensity of the light at the lamp house.

We have now described briefly the constant potential system of electric light supply.

RESISTANCE OF AN ARC LAMP

An arc lamp, if kept at constant potential, will have a fixed and unvarying potential difference of voltage kept between its terminals. By Ohm's Law the current passing through it under this condition of unchanging voltage will depend upon its resistance. But as there is nothing fixed about the resistance of an arc lamp, there will be nothing fixed about the current passing through it, under the condition of unchanging voltage. With no other control the light would vary without any action on the part of the operator.

Hence it is evident that the constant potential system of electric light circuit, on its face at least, is not the ideal one for an arc light of constant candle power, yet by the introduction of the rheostat or of the choke coil in the circuit and in series with the lamp, this system is made to operate the light in the lamp house perfectly.

The above applies to arc lights. If the projection apparatus is operated with an incandescent lamp, it is in constant potential that the best conditions for its use will be found.

THE THREE WIRE SYSTEM

A power station constructed to supply a sufficient current to take care of the requirements of a district, and operated to keep an unvarying difference of potential between the bus bars in the station, may work at the standard potential of 110 volts. This generally would be the minimum; the resistance of the lines would require a slightly higher potential at the station. It might start at 114 or 115 volts, and out in remote parts of the district show only the regulation 110 volts.

The lines would start out from the station in pairs. Now let the station be run at double the lamp voltage of 110 volts, as we are taking it, and let the lines go out in sets of three. Next assume that there are 220 volts potential difference between two of the wires. These wires we will call the outside wires. Then let the third or neutral wire be kept at a point half way between the two outer lines as regards potential. The lamps are connected from one or the other outside line to the neutral line. This gives a lamp the proper 110 volts, although double this potential is developed at the station and carried through this district.

Returning to our ladder comparison we have here a ladder with side and center pieces.

A number of conditions may arise on such a system of distribution, which we will look into. The system is the three wire system; it is the invention of Edison.

Balance in the Three Wire System

First assume that there is an equal number of lamps lighted on each side of the three lines. This condition is shown in the cut. In such case no current would pass through the neutral line. The condition would be the same, as if each pair of lamps were connected in series with one another, and were supplied with 220 volts potential.

If one lamp were extinguished the balance would be destroyed. The circuit with an equal number of lamps lighted on each branch as just described is said to be balanced. For a balance the lamps on one branch must take the same current as those on the other.

Suppose the lamp extinguished took a current of one ampere. Then the neutral wire would have to pass a current of one ampere. If lamps requiring more amperes were extinguished on the same branch the balance would be still further impaired, and the neutral line would have to pass the current which these lamps passed when in operation.

Load Carried by Neutral Wire

The load to be carried by the neutral wire depends on the difference in current required by the branches. If fifty lamps of one ampere current consumption were on one branch and forty-nine on the other, the neutral line would have to pass one ampere. If there were only one lamp lighted, again the neutral would have to pass one ampere.

Object of Three Wire System

The object of the three wire system is to save copper; the three conductors are supposed to do the work of four. This they will do if the same number of lamps is lighted on both branches. If only one branch is active the entire current has to be passed by the neutral wire and the system is practically a two wire system. The assumption is made in using the three wire system that the load on the neutral wire will be relieved by a more or less even balancing of the lights.

A three wire circuit is in balance when each branch is taking the same number of amperes. There is no need for the lamps to be of identical size; it is a question of the sum of the amperes consumed.

The same idea has been carried out so as to give five wire systems. These have one neutral wire and two partly neutral and two active wires. The five wire system is not much used.

The three wire system of electric distribution is a direct current system of electric supply, one sometimes used in cities and communities, where the alternating current has not been adopted. The term applies to a special system of distributing direct current; sometimes three wires are used in the distribution of alternating current, but that is the three phase system, quite another thing from the three wire system.

Installation of Three Wire System

If two wires are taken from the extremities or poles of a battery we all know that if the wires are connected a current of electricity will flow from one pole of the battery to the other. Now suppose two batteries identical in all respects are placed side by side and connected in the regular manner, positive to negative pole, and then let two wires be taken from the outer poles of the two, we will have again an open circuit, such as we had before. If the two wires are connected a current will flow. A number of lamps could be connected across the wires, from one to the other, like the rungs of a ladder, and each lamp would receive current. The potential of each lamp would be that of the battery diminished by the action of the resistance of the wire conductors. This is a two wire system. Now imagine that a wire conductor is carried from or connected to a point between the two batteries, and is carried through the line of the conductors along with and parallel to the original two. This would be a three wire system.

Of course in actual practice the current is generated by dynamos, not by batteries. Two dynamos are installed. They are connected in series, just as the batteries were, and three conductors are taken from them through the district. One wire or conductor is connected to the negative pole of one of the dynamos; a second conductor is connected to the positive pole of the other dynamo, both poles being the outer poles of the pair of machines. This gives a two wire system of double the voltage of a single dynamo of the two. Both machines are supposed to be identical. A third conductor is connected to the point intermediate between the two dynamos. This conductor is in connection therefore with the adjacent positive pole of one machine and the negative pole of the other one. This conductor goes through the entire circuit parallel to and along with the other two. The arrangement constitutes the three wire system. It is not applied to batteries, but the battery connections described were a true three wire system, and were used to make the reader understand more readily what the system is. It will be seen that there is no mystery about it. The wires first spoken of are the outer wires of the system; the third wire is the neutral wire or third wire by name. Let us suppose that the potential of a single one of the pair of machines is one hundred and ten volts. Then there will be a difference of potential of two hundred and twenty volts between the outer conductors. This is the sum of the potential of the two dynamos. The potential difference between the neutral wire and either of the other two is that of a single dynamo, one hundred and ten volts. One hundred and ten volt lamps are connected across from outer wire to neutral on both sides. The object is to have as nearly as possible the same number of lamps in action on each side of the system. If there are the same number the system is said to be in balance.

Double Voltage Connections in Three Wire System

Motors and special appliances or connections can be made across from outer wire to outer wire. Such appliances receive twice the voltage of a single machine, or two hundred and twenty volts. With a perfect balance the neutral wire has hardly any current to pass. If each pair of lamps were connected directly opposite to each other it would be quite idle. The three wire system is based on the assumption that there will always be an approximation to equal distribution of lamps and appliances on both sides of the conducting system. Therefore the third or neutral wire is made of considerably smaller size than the other or outer wires. It would be almost an impossibility that the lamps should all be lit upon one side so as to throw the full load on the neutral wire. The saving of copper thus brought about is the object of the system. Not only do three wires do the work of four, but one of the wires is smaller than the other two. It produces a saving of over one quarter of the copper.

Installation of Five Wire System

The same idea has been pushed to a further extent in the five wire system. In this arrangement two more dynamos are placed in series with the two of the three wire system; conductors are taken from the extremes of the system and from the points between each pair of dynamos. The central wire is the neutral one; the other wires are more or less active, those nearest the neutral less than the outer wires. The five wire system is quite exceptional in this country, and is not to be considered as a possibility in projection practice.

In the three wire system too great a draught upon one side of the system may produce great variations in the potential of other connections; the lighting of the lamps of a projector may be enough to give trouble among other consumers. In a small place, where the lighting system is of limited capacity the best way is to connect the motion picture circuit to the outer wires.

This will give a potential difference of about two hundred and twenty volts. The potential is reduced by a rotary transformer at little loss and the element of disturbance is disposed of nearly completely.

Such are the outlines of the three wire system. The tendency now is more and more towards the installation of the alternating current in cities, and it is this system, which will generally be met with. But it is well to realize that there is nothing mysterious about the three wire system, and to know what it is.

CHAPTER III

THE FIELD OF FORCE

WHEN a current of electricity passes through a wire or any conductor, it affects the space around it, in its magnetic relations. It was early in the last century that it was discovered that if a current of electricity passed through a wire, a compass needle held near to the same conductor would tend to place itself across it, and this without touching it. It was also found that if two wires carrying currents in the same direction were placed parrallel to each other, they would attract each other. Next it was discovered that a wire carrying a heavy current would retain iron filings in contact with itself as long as the current persisted. Other similar observations were made, showing that the space around a conductor carrying a current was affected. It was found that the effect was subject to exact mathematical laws, and a unit to express the effect of a current of electricity on the space surrounding it was needed. A unit was taken and called a line of force. The strength of the effect produced by an electromagnet for instance is stated for any place where its effect can be felt, as so many lines of force per square inch or per square centimeter or per other unit. The value of a line of force is based on the effect it exerts on a magnet pole of unit strength at unit distance from it, with a unit length of its conductor. There is no need for the subject of the theoretical value of the line of force to be gone into any further here.

LINES OF FORCE AROUND A CONDUCTOR

The lines of force surrounding a conductor or a wire carrying a current may be figured as a set of circles lying at right angles to it. There is no limit to their number; they are larger and larger in diameter as they are further from the wire and have less and less strength as they are larger. Just as different metals have different conductivity for electric currents, iron of different qualities has different powers of carrying lines of force. Most other substances than iron are all practically equal to one another in this power, and are very much inferior to any kind of iron. The quality of carrying lines of force or of affording them a path is called permeability. If a soft iron carries them better than a hard steel, it is said to have higher permeability. The permeability of a piece of iron of given shape and size is termed its permeance.

The collection of lines of force in any place contiguous to a current is called a field of force. To produce a field of force the most advantageous method is to carry the current in a series of turns around a core of iron; to wind an insulated wire around an iron core and to pass a current through the wire. This the reader will recognize is an electromagnet, with which all are familiar.

POLARITY OF THE ELECTROMAGNET

The simplest form of electro-magnet is the straight cylindrical core of iron, surrounded by a quantity of insulated wire, through which a current of electricity is passed. The effect of the current is to create a field of force, whose lines go through the core of the magnet and then return after emerging from one pole, back to the other pole, this time through the air. Now suppose a second magnet is brought near to the end of the first one. We have seen that currents passing in the same direction attract each other. It is also the fact that currents passing in reverse directions repel each other. Therefore if our two magnets are placed end to end they will attract one another if the currents in their coils are flowing in the same direction in both. If the current in one flows in the reverse direction of that in the coils of the other one, they will repel each other.

If the end face of a magnet is held in front of an observer, and if the current in its coils goes around the core in the direction of the hands of a watch, it will be the south pole, and the lines of force are assumed to enter the south pole, to pass from it through the core to the north pole and then to emerge and return through the air.

If two south poles are brought face to face, the currents in their respective coils will flow in opposite directions in each. Therefore the two poles will repel each other. If a north pole is brought to face a south pole the current in the coils of each will flow in the same direction, and they will attract each other. We have not to deal with natural or permanent magnets in this book. It may be said here that Ampere's theory of magnetism assumes that a permanent magnet, without any coils around it, has currents of electricity flowing around its molecules, so that the attraction of north pole for south pole and the repulsion of like pole by like is due to the action of these "amperean currents." Under the same theory the earth is supposed to have currents of electricity circulating around it, approximately parallel to the equator, and exercising a directive action on the compass needle.

Horse Shoe Magnets

Thus far only a straight cored magnet has been spoken of. The iron core may have any shape. If of the shape of a letter U, or of three sides of a square it is called a horse-shoe magnet. This is a very old expression, going back to the early days of the last century, and never has been dropped. Certainly a magnet core made up of two straight legs connected by a straight bar across their ends, so as to form a three sided rectangle is not much like a horse-shoe. If the legs of such a core are wound with insulated wire, we have one of the commonest forms of electro-magnet. If such a magnet is caused to attract a bar of iron with both its poles at its open end, the bar spanning the space between them, the lines of force are given a complete path of iron for their passage. This they will concentrate in, the magnet will hold the bar firmly in place, and we have what is called a complete magnetic circuit. There is, however, a leakage, greater or less, of lines of force from the magnetic circuit, depending on its shape and relative thickness of the core; for even the shape has to do with the percentage of leakage, a smooth rounded form giving a good circuit, with small leakage of lines of force.

Energy in Building up the Magnetic Field

If a current is connected, so as to flow through a magnet coil, through which no current has been flowing, energy will be expended in building up the magnetic field, as it is called. This building up requires only the small fraction of a second, yet energy is required. Such energy may be measured in volt-coulombs, or in volt-ampere-seconds, the latter being better termed watt-seconds. This fact, that energy is required to build up a field of force, has important bearing on the action of alternating currents. As it takes energy to build up a field of force, it will be clear that the new field of force, as it is building up, is opposing the action of the current, and holding the current back. This action is a form of what is termed counter electromotive force.

SECONDARY INDUCED CURRENT

Now suppose we have some arrangement of circuits, by which we can increase the number of lines of force passing through a coil of wire. If the ends of the wire are connected, so as to form a closed circuit, a current of electricity will flow through the wire, it may be for only a minute fraction of a second. Such a current is said to be induced, and it lasts only as long as there is a change in the strength of the field; the instant the field becomes of constant strength, the current ceases. In electric generators, a variation on this action is used to induce current. Not only does a change in the strength of a magnetic field in which a wire or conductor is placed induce a current, but if the field is constant and the wire is moved through it, so as to cut the lines of force, of which it is composed, the identical induction of current will take place.

In practice it is always the induction of current that is spoken of; it would be more accurate to refer such action to induction of electromotive force.

ACTION OF A DIRECT CURRENT DYNAMO

A direct current dynamo acts in two ways; it maintains a field of force, and the rotation of its armature carries the windings of the armature through the field of force, so that the wire on the rotating armature cuts the lines of force. This induces e.m.f. in the windings of the armature, and if the ends of the wire on the armature are connected, so as to form a closed circuit, a current will flow through them. The strength of the e.m.f., and consequently of the current induced by this cutting, is in direct proportion to the lines of force cut per unit of time. To get a good effect the field of force in practice is made as strong as possible, and the windings on the armature are more or less numerous according to the requirements of each case.

In dynamos and motors it is a great object to have as good a field of force as possible, and this is the same as saying as perfect a magnetic circuit as possible. The magnetic circuit is made a good one by making its core of good quality of iron, as thick and short as possible, and with as small a space between the magnet core and the armature core as possible. The armature of a dynamo or motor is also to be considered an electromagnet. It is wound with a continuous coil of wire, so that in itself it is closed and without any outside connection. But its windings are tapped by the brushes at two places, diametrically opposite each other, which arrangement converts the closed circuit winding of the armature into a parallel winding to be closed by a conductor on the outside circuit. If a current were sent through the windings of an armature, as the wires lie on the core, with no brushes touching the commutator, there would be no magnetic poles discernible in the armature. But when a current is sent through in two parallel paths north and south poles are formed on the armature and it becomes an electromagnet. It is held in a field of force; its poles are attracted by those of the field cores; the brushes are so placed that they, as they shift from bar to bar of the commutator, also shift the poles of the armature. In this way the armature core is constantly attracted and rotates on its shaft.

The Alternating Current

An alternating current is one, which changes its direction repeatedly at short and mathematically regular intervals. The current starts at zero or no value, it then regularly increases to its maximum, and then descends again to zero. So far the current has risen from zero to the full value and has gone back to no value. Here it does not stop. It now starts to again increase but in the other direction, and repeats exactly what it has gone through but in the reverse direction.

The Cycle

What is described constitutes a cycle. In ordinary practice there are sixty cycles in each second. There is a wide range of this factor; the figure, sixty, is the general one here; at least there is a tendency to adopt it in public service installations.

FREQUENCY

The number of cycles in a second is termed the frequency of the system.

Two or three independent sets of phases may be sent out on the line, involving the use of three or four separate conductors. Such sets constitute two and three phase systems. A single set of phases is the simplest and this constitutes a single phase system, and requires two conductors only, just as a direct current system does.

The direct current system is controlled by resistance in the form of rheostats. In such resistances voltage is expended to maintain the current, and this voltage implies waste. To determine how great the waste in any regulating resistance is the voltage absorbed by the resistance must be multiplied by the current passing through it. A resistance may involve very large loss of power; it always involves some. It cuts down the current at the expense of economy. It is as if it cost money, at so much an hour, to shut off a water supply.

ALTERNATING CURRENT AND DIRECT CURRENT

There is a disposition on the part of many to consider the alternating current of electricity, A.C. as it is expressed in abbreviated form, a special modification of the direct current. This is a minor matter, especially from the practical standpoint, and the latter is what concerns us here. But the true way to look at it is to consider that the A.C. current is as individual and has as distinct an individuality as the D.C. current. Some even give it a sort of precedence, and start with it in treating the subject of electricity, and assign a position to the direct current as an offshoot of the alternating.

It is needless for us to describe the winding of an alternating current dynamo. It is enough to say that the wires of the armature of a dynamo in general have electromotive force of polarity adapted to impress alternating e.m.f. and hence alternating directions of current on the windings as their relations to the poles of the field, past which they are rotated, changes. If the ends of the armature windings are connected to a circuit will have impressed upon it alternating electromotive force, and if the circuit is closed, an alternating current will pass through it.

The letters D.C. and A.C. are used to indicate direct current and alternating current.

CONNECTING RINGS

The connection of the outside or working circuit with an alternating current dynamo is of the simplest description; two rings are fastened to the shaft but insulated from it. On each of these rings a carbon or copper brush rests as the shaft rotates, and to these the circuit is connected. Alternating potential is thus collected by the line of the circuit. There is no complicated commutator as in the direct current generator or dynamo. The mechanical part of the installment is simpler than in the case of the direct current generator.

ALTERNATING CURRENT IN PROJECTION

The alternating current in many ways lends itself so much better to the solution of the problems of distribution and regulation that it is constantly displacing the direct current installations, being installed in places where at one time the D.C. current would have been used.

The desideratum, in the projection of pictures is to have a light, which is of intense brightness and is of as small area as possible. The crater of the D.C. arc fulfills these requirements fairly well. Recent improvements are in the direction of the production of a still smaller D.C. crater of great brilliancy, so that the D.C. arc, it is fair to say, is, as regards quality, the best of all lights for projection purposes.

When we come to the A.C. arc another condition is to be met. The crater in the D.C. arc is formed because of the different conditions under which the positive and negative carbons are consumed. All this is described under the subject of the direct current arc. But in the A.C. arc both carbons are consumed under identical conditions. One burns or wears away as fast as the other; the points of the carbons are symmetrical and alike; there is no difference of crater in either one; the light is due to the two carbons in equal degree. There is no preponderance of light production by one carbon as in the D.C. arc. In quality, other things being equal, it is fair to say, that the direct current gives the better arc for the projection of pictures.

The power of an electric system is measured by the watts. These are the product of volts by amperes. Now the electric current lends itself to very easy changes, because the voltage can so easily be changed. If Ohm's Law is understood the reader will know that to change the current in a conductor, the voltage producing the current must be changed, if other conditions are undisturbed.

Changing Voltage of an Alternating Circuit

Suppose that the conditions on an outside public service line were such, that on connecting a projection circuit to it, too heavy a current would be produced. If it were a case of direct current, the obvious way to cut down the current would be to increase the resistance of the line within the building, when less current would flow in accordance with Ohm's Law. There would be no attempt to change the voltage impressed on the lines within the projection booth. Their resistance would be increased, so that the street voltage could not force too heavy a current through them.

In the case of the alternating current the same problem is attacked otherwise.

Two things are required to produce an electric current; one is electromotive force, e.m.f. or voltage, the other is a conductor for the voltage to act upon. We have seen that to change a direct current's strength the simplest and most obvious way was to change the resistance of the circuit. But to change the intensity of an alternating current in a subsidiary circuit a transformer can be used, not to change the resistance of the circuit, but to change the voltage acting on that circuit. It is a most fundamental way of getting at the desired result.

Let the outside or street circuit be supplied with a voltage of 115 volts. Then let the resistance of the circuit in the building be one ohm. The current would then be $\frac{115}{1}$ or 115 amperes.

This is an application of Ohm's Law. If the current required was 30 amperes, all that would be necessary would be to reduce the voltage on the inside line, by a transformer. The resistance of the inside line would not be changed except to the extent that it might be modified by the windings of the transformer.

The transformer is a perfectly inert and motionless apparatus; no power is expended in operating it, and except for its own inevitable resistance it operates by directly changing the voltage impressed on the inside or house circuit.

The transformer is left permanently connected to the street circuit, but as long as the inside circuit is open, very little current goes through it. The full voltage of the outside circuit is impressed upon it, but no current of any amount can pass as long as the inside circuit is open.

Any voltage desired can be tapped off from it by proper windings on it. Nothing in direct current work corresponds to it. It is a pity that the best current for a projection arc lamp is the direct current, which does not so readily lend itself to easy and perfect control.

The Transformer

If a wire is wound around a core of iron, and a direct current is passed through the windings, the core will be magnetized, because lines of force will be created in it, and it will become a magnet. It takes a certain amount of time to build up the collection of lines of force in and about the iron core, as we have already seen. The time is very short, and varies with the factors of inductance and current strength. It also takes energy to build up the lines of force. Let an alternating current act upon the same core of iron. The alternating current has two polarities, in each of its cycles. As the alternating current starts from its base line or from its zero value it increases to its maximum value and again recedes to zero value in the one-half of its cycle. All this time it is of one polarity. After reaching its zero value once more it begins to grow in strength to the same maximum as before, but this time of the opposite polarity or opposite direction of current. These two changes may be produced in the sixtieth of a second. The time may be much less or much more; a sixty cycle current is usual American practice.

THE CHOKE COIL

Let a circuit carrying such a current be connected to a coil of wire wound around a core of iron, preferably of iron wire or of thin plates of the same metal. As the current started to go through the windings of the coil of wire surrounding the core, it would be met by counter electromotive force. This would operate to hold it back and a certain amount of time would be required to overcome this force. To overcome it would involve the building up of a field of force, and this would require a definite amount of energy. For the current to exert any definite amount of energy a definite amount of time would be required. This is because energy is measured by volt-coulombs—the current is transporting a certain number of coulombs in each unit of time, so that the necessity of the element of time in the process is clear. But before the current would have time to exert any tangible amount of energy on the building up of the field of force, its polarity would change and it would have to begin all over again, as it may be expressed. Taken from this simple point of view it is clear, that an alternating current is held back or "choked" by such a coil. What a choke coil, as it is called, does, is this; it prevents the alternating current from exerting energy, and holds it back in a most economical way. If the coil is large enough and properly proportioned there will be hardly any loss of energy in its use as a reducer of the strength of an alternating current. This is far different from the action of a rheostat or resistance on a direct current, where there is a direct consumption of energy, depending on the resistance of the rheostat or other resistance.

A small choke coil will allow a considerable amount of alternating current to pass, so that it may be used to reduce current to any desired amount. This is not an economical way of working, however, and is not much used.

THE SECONDARY WINDING

Next suppose that there is a second winding on the iron core. Again let the alternating current act upon it. There is no difference as long as the second winding is not continuous, but is on open circuit. But let its ends be brought in contact, so as to convert it into a closed circuit. As the original current acts upon the coil in its circuit, the primary coil it is called, as fast as it starts to develop counter electromotive force, the other coil, the secondary coil, absorbs the e.m.f. in question, and a current goes through it. The secondary winding takes the choking power out of the coil, as long as the secondary is on closed circuit. This arrangement constitutes a transformer. The description is far from scientific, but is designed to give the general idea of its operation.

But this is not all. The voltage on the circuits of the two currents, of the inducing or primary and of the induced or secondary current, varies in proportion with the relative number of turns of wire in the coils. If there are twice the turns in the primary as in the secondary the voltage on the secondary circuit will be approximately half that on the primary, and vice versa. It will be clear how well adapted the transformer is to projection work, where the voltage of an alternating circuit has to be reduced; it is all a matter of the relative number of turns in the two coils what voltage shall be delivered to the lamp.

The plain coil of insulated wire, wound on a core of iron and placed in series with an alternating current generator, and operating to cut down the current to almost a zero value, is called a choke coil. It exacts the formation of a magnetic field from a current passing through the windings of its coil, and is said to possess inductance.

When to the primary or original winding, which is the coil of a choke coil proper, a second winding is added on the same core, the choke coil becomes a transformer. The choke coil winding is the primary winding and the other winding is the secondary winding.

THE AUTO-TRANSFORMER

This is about the simplest of all contrivances for enabling us to take various currents from an alternating circuit run on constant potential, and its action will be understood from the preceding paragraphs.

Around a heavy core of soft iron, wire or thin sheets, built up into a proper shape, a quantity of insulated wire is wound.

There is no particular shape for the core; it may be made in many ways. If the terminals of the winding of the core are connected to an A.C. circuit, very little current will pass, the contrivance acting as a choke coil.

Next to any two parts of the winding let the ends of a closed circuit be connected. The effect will be to reduce the choke action of the coil, and the branch circuit will pass a current. This current will be due to the electromotive force impressed on the circuit, which will depend for its tension on the number of turns of wire winding included between the points of its connection to the same winding.

If the connections are so arranged that these points of connection can be changed as desired, the auto-transformer will become a most convenient appliance for changing the potential of a circuit.

Unfortunately it is not very economical; it is used principally for smaller work, where heavy currents are not taken from it.

It could be used for the regulation of a projection lamp by connecting the terminals of the lamp circuit to its extreme ends, so that the lamp circuit would be unaffected by it. Then by shifting the connections the lamp circuit could be controlled by the use of but a very small section of the windings and in this way economy would be secured at least as far as the auto-transformer is concerned. Of course this implies that the original potential of the main circuit shall be not too far removed from that required by the lamp. The auto-transformer will only give it the last touch in the arrangement suggested.

An operator might want a current of 50 amperes to flow through his circuit. If he was depending on alternating current, the transformer would effect what he desired with a very slight loss of efficiency.

CHAPTER IV

THE MOTOR GENERATOR

WHERE direct current is used to supply a projection lamp from the public service line the voltage will be too high and will give too strong a current if it is allowed to supply the lamp directly. The action of the rheostat in cutting down the current in a most uneconomical way is often used to reduce the action to the limits of the projection arc lamp. As an advance on this practice the motor-generator is employed. There are several kinds.

One is a very simple appliance; it is a motor operated by current from the mains at full potential between its terminals. On the same shaft with the motor and utilizing the same iron armature core is a second winding, the generator-winding. Each winding has its own commutator. One takes the current with a potential difference of the full street pressure between the brush terminals. Operating as a motor it turns the double wound armature and generates potential difference in the other coils of the armature. This potential difference is much lower than that of the public circuit; the windings of the generator-sections of the armature have fewer convolutions than those of the motor-sections so as to reduce the potential difference between the generator brushes. It is from these brushes that the current for the lamp is taken, and they generate a potential on the lamp circuit, which is much lower than that of the regular public service circuit.

BALLAST RESISTANCE IN MOTOR GENERATOR

A generator and a motor both run at quite high efficiency, so there is little loss between the high voltage supply and the low voltage delivery of the motor generator. It is not quite enough to do the whole work of regulating the lamp current. A small resistance rheostat, termed a ballast rheostat is connected in a series with the lamp on the circuit coming from the generator end of the machine. This in addition to the generator takes care of the operation of the arc lamp.

A motor generator is often an electric motor which runs in company with a dynamo or generator. Usually the two are mounted on the one bed-plate and have one shaft for both. The motor may be alternating or direct current and so may the generator. In those made for projection as the object is to use D. C. for the lamp, if possible, it will be taken for granted that the generating end of the dynamo of the combination will be a D. C. machine.

Wastefulness of Rheostat

It is very wasteful, when working on a direct current circuit, to rely upon a rheostat to reduce the current to working intensity. About one half the power is lost in such cases. This brings us to the advantage of the motor-generator, which is D. C. at both the motor and generator ends, and whose function is simply to reduce the electromotive force or voltage supplied to the lamp. This machine is a combination of a motor, wound for the voltage of the service line, and actuating a generator, which gives the voltage of forty to sixty volts, such as may be required by the lamp circuit.

Two Constructions of Motor Generator

Two constructions are to be had. In one the axle or shaft is vertical. This construction is compact as regards floor space taken. It requires a special end bearing, as the entire weight of the rotor, practically always the armature, has to be carried by it. In the more conventional construction the shaft is horizontal, and ordinary bearings are employed.

If we refer the operation of the motor generator to a single lamp, it will be evident, that as service circuits are now operated, the action of the machine will be to reduce voltage. If two lamps are in parallel, the generator will supply a voltage of say sixty volts, and will perhaps be driven from a 110 or 220 volt circuit.

But the lamps of the projection machines may not be connected in parallel. If connected in series each requiring its sixty volts, the generator will be called upon to deliver a voltage of one hundred and twenty units. On a 110 volt circuit the motor generator would have to increase the voltage in such a case, building it up from 110 to 120 volts.

It will be clear that there is a wide range of action, which can be provided by the motor generator.

The Converter

When a machine of this type is run to simply change voltage it is properly termed a motor generator or a dynamotor. When it is run to convert an A. C. into a D. C. it is properly termed a converter.

The A. C. and the D. C. generator, as they appear in the combination of the motor-generator or converter, are of much the same construction. Both require a solid cylindrical drum core armature, which revolves in a field of magnetic lines of force. This field is formed by an electromagnet, which has a massive core of soft iron, with a cylindrical space, within which the armature revolves. The armature has a massive core; it is a cylinder of laminated iron. Discs of thin soft iron are cut out by machine, each the duplicate of the others. They are of circular contour, with slots, radially disposed and evenly spaced around their periphery. There is a hole in the center of each disc, to receive the shaft. They are strung upon a shaft, the grooves or slots, all accurately in line, so that the collection gives a cylinder of iron, with slots along its surface, and firmly fixed on a shaft so as to be practically a solid structure from the mechanical aspect. But it is laminated really, as it is made of thin discs of soft iron. The effect of making it of discs is to break the magnetic continuity in the direction of its length. The iron discs are more or less oxidized, it may be imperceptibly, but it is enough to make a break in the core magnetically considered, so that lines of force will not have a path of metallic iron parallel to the axis of the cylinder. A magnet, whether an electromagnet or a permanent one, is supposed to create a field of force; lines of force are supposed to emanate from each pole and to seek a path to the other pole, always choosing or rather seeking for paths of the least resistance. Of all materials iron is almost alone in giving a good material for paths of magnetic lines of force. Nickel and cobalt, among all known substances, approach the nearest to iron in their low resistance to the passage of magnetic lines of force. But although these two metals have some resemblance to iron in this property, they are very inferior to it; so much so are they, that, from a practical standpoint, they receive no consideration, and are regarded as having no special permeability which is the power of passing lines of force. It is somewhat analogous to the power of conducting an electric current. As copper is a better conductor of current than iron or lead, so is iron a better material for the passage of lines of force than any other substance.

In the field of electric current transmission some conductors are better than others; when it comes to the magnetic field and to the transmission of lines of force, there is only one material that is ever considered, and that is iron.

The property of conducting an electric current is called conductivity; the property of conducting a line of force is called permeability. Different samples of iron vary among themselves in this power, so we have good and inferior substances for the carrying of the field of force, but all the materials are iron. In general, the softer the iron the better it is.

Commutators

The commutator of a generator or motor is an all important part of the machine. It should be absolutely true in contour, being a perfect cylinder, without ridges or flat surfaces on its surface. The narrow spaces between the bars are filled with mica as an insulator, and it sometimes happens that this projects so as to cause an irregular motion in the brushes, and this irregularity causes sparking. The mica should be undercut, as it is termed; this means that is should be so cut away as to have its surface about a sixteenth of an inch below the surface of the copper bars of the commutator. It should be so cut as to present a flat surface, and not a grooved one, in which latter the mica would be lowest in the middle and would rise up on each side level with the metal of the commutator bars.

Mica in Commutators

If the surface of the commutator has worn away by long service, it may happen that the mica, which is untouched by the brushes owing to its position, may be brought near the surface and in places even with it. This is the beginning of trouble, for the sixteenth of an inch depression should be preserved. It is an insurance against projection of the mica, and jumping of the brushes. If the mica is approaching too close to the surface of the commutator, it may be cut away with a hack saw. In using this tool care should be taken to keep it level or parallel to the axis of the shaft of the armature, and to work it to right and to left in the successive strokes so as to remove the mica as evenly as possible for its entire width. This is a very small measure, a small fraction of an inch and it would be quite possible to extemporize a saw blade of the proper width or gauge to plane the surplus mica away in a few strokes for each place. If the gap between the bars is unusually wide, it may be possible to clamp two blades together in the one holder and thus produce a blade, which will exactly fit the space and remove the mica in one operation to its full width. If on the other hand the single blade is used and if it is not of the full size of the slot, it must be worked to right and left by hand so as to cut away the mica on the sides.

The operation is simple because there is so little depth to be attained and the hard copper bars of the commutator are guides for the saw. The ideal saw blade for the purpose would be one with no set to its teeth, and with the teeth filed straight across, so as to act like a milling cutter straightened out, or like a multiple plane tool. A special file is sold for this use.

It is not too much to say that the running of a direct current machine depends on two things principally, and of these two things one is about as important as the other. The first is the commutator surface. If this is out of shape noise, sparking, and irregular potential may result. The other is the shaft bearings, which will be spoken of farther on.

Bars of Commutators

Assuming the mica to be in place, with the surface below the bars of the commutator, the bars themselves must be of even height, so as to form the surface of a perfect cylinder, except for the breaks in continuity between them. There are several things, which may occur. A flat, as it is called, may develop on the surface. One or more bars may wear away so as to produce a flat surface over which the brushes will pass with a noise or slight jar, detrimental to the working of the machine, which should be the perfection of smoothness. The reverse may happen. One or more bars may be too high and a high spot may develop, which will cause the brushes to jump as they pass over the projection. This too is objectionable. As long as the commutator seems to be in good shape, and the brushes work quietly, it is best to leave it alone;

if it is seriously out of shape you will infallibly know it. If it does get out of shape the treatment is simple or not according to the amount and extent of the irregularities.

GROOVED COMMUTATORS

There is another defect, which may form on a commutator, and not reveal itself for a long while. If the carbons follow the same paths without variation, they may wear grooves on the surface. Eventually these will declare themselves, but they may go a long ways first. They are avoided by the slight right and left motion of the armature in its bearings, which motion prevents the brushes from following the same path; sometimes they will go to the right and sometimes to the left. If the rotating armature is closely observed this lateral motion can be seen, and it may seem as if it were a fault in the construction. It really is an advantageous feature, as it is this which prevents the brushes following the same path and grooving the surface of the commutator.

The commutator should be watched for sparking and heating and at the first sign of trouble it should be treated for its cure.

SANDING COMMUTATORS

"Sanding" or rubbing with sandpaper is the simplest treatment for a commutator. This consists in polishing it with a piece of very fine sandpaper. On no account must emery cloth be used, as it may do lasting injury. A convenient sized block of wood must be cut to the circle of the commutator, or a trifle larger. A piece of sandpaper is placed on the commutator and the block is pressed down on it by hand and worked to and fro and from side to side to remove any roughness and bring the surface to the proper cylindrical shape. If it is a generator the work is comparatively easy, for it can be slowly turned by its motor, while the sandpaper is pressed against it and moved laterally so as to cover in its travels the whole surface. The tendency is to produce a cylindrical surface, which is what is desired. Even if it is a generator whose surface is to be sandpapered, it may be possible to have it rotated by some arrangement or possibly by hand, if it is not too hard to turn. There is no question that the best way to polish the surface of a commutator is to do it while it is kept slowly rotating. It acts as if it were turned between centers on a lathe.

The surface of a commutator acquires a dark tint with time. This affords a good guide for the sanding process. Where the sandpaper acts it removes this discoloration, so the person doing the work can tell where the sandpaper is giving results. A few minutes work will show where the high spots and where the hollows are. The high spots will be brightened, the low places will be unaffected for a period depending for its length on how bad the condition of the commutator is.

Before beginning the papering the brushes must be removed. They are not to be disconnected from the pigtails, as the short connections between brush and holder are called. The brush holders will afford a brace or sort of steady rest for the grooved block to bear against. The block should be over half the width of the commutator, three quarters the width is the least it should be. The idea of having it so wide is to avoid forming grooves around the cylindrical surface. The brushes may do this. If they have done so, then a reasonably wide polishing block will disclose the grooves by polishing rings or bands around the commutator. It may be beyond the power of the sandpaper to get rid of them. Always in applying the sandpaper keep the block in constant motion parallel with the shaft of the armature, or more harm than good may result from the polishing.

When the sanding is finished, it will be shown by the appearance of the face of the copper. It should be of even polish and color all over. The next thing to do is to wipe it off thoroughly to remove any copper dust and grit due to the sandpaper from its surface. The slots should also be cleaned out with a stiff brush, such as a tooth brush.

SANDSTONING COMMUTATOR

If the commutator is very rough and in bad shape, it may be that the sandpaper treatment will not be enough. For such cases it may be advisable to use a block of sandstone, such as grindstones are made of, and to polish it with this, using the brush holders or some extemporized appliance to brace the stone against, steady rest fashion. A specially mounted stone with a handle is provided for this purpose. It should properly speaking have a cylindrical concave surface to fit the commutator, like the sanding block. The trouble would be in such a construction, that the hollow would not hold its shape. After the application of a stone to the commutator, the latter must be polished with fine sandpaper as just described.

FILING COMMUTATOR SLOTS

A special file is sold for cleaning and deepening the slots between the commutator leaves. In buying such a file be sure that it fits the grooves and that it is neither too wide nor too narrow. The latter is a minor fault. If too wide it is absolutely useless.

The removal of copper dust from the slots of the commutator is necessary to prevent short circuiting, for copper dust and little fragments of the metal may bridge the interval between two bars and occasion a leakage of the current.

TURNING COMMUTATOR ON LATHE

If the commutator is so badly worn that neither stone nor paper will correct its irregularities. the next thing is to have it put into shape on a lathe. To do this it is the general practice to place the armature on a lathe, and turn it off. This is rather a critical operation. A sharp tool must be used, taking off the lightest possible cut, and the lathe must be run at high speed. Next the mica should be cut down, because the turning has inevitably brought the mica nearer the surface. Sanding as described follows, so as to remove all the tool marks left by the lathe tool, the grooves and the surface all cleaned and a final inspection is given to see if any copper chips are bridging the slots.

The sanding of a commutator is a simple thing to do. It may not leave it in perfect shape, but it will demonstrate the need of more radical treatment if such is required. The turning down the surface so as to actually true it up, is a mechanic's job. The General Electric Company treating of the subject of commutators thus express their view on the subject of commutators:

"The truing of the commutator should be required only after a long period of service if the machine has been properly cared for and should be done only by some one familiar with such work."

MOTOR AND GENERATOR BRUSHES

The brushes on a motor or generator of the direct current class require attention. They are held in tubular sockets, in which they are free to move up and down. To ensure this freedom they should be taken out of the sockets from time to time and the interior of the sockets should be cleaned. The General Electric Company recommend weekly cleaning of this sort. The great point is to replace the brushes properly, as otherwise they will not fit the curve of the commutator. Do not remove the pigtails from the brush holders. The surface of the brushes which bears against the commutator should have a smooth unscratched surface, free from any film of copper. They must make good electric contact with the copper bars of the commutator without picking up copper from them. If the holders have to be oiled the less that is used the better will the electric contact be, and there will be less danger of gumming up with consequent stiff or clogged motion of the brushes than, where more oil may have been used.

The brushes are pressed against the copper commutator bars by springs. There should be just enough pressure on the brush springs to insure good contact between brushes and commutator.

There should be about a sixteenth of an inch end motion to the armature to prevent the brushes following the same paths; this feature tends to secure a cylindrical and ungrooved surface.

The brush holders should be securely fastened at a height of a sixteenth of an inch from the surface of the commutator. The object of having them so close is that they may support the carbons and prevent them from breaking. The holders must be so spaced as to secure an equal distance from tip to tip of the brushes, measured around the curve of the commutator.

When putting in new brushes the bearing surfaces have to be fitted to the commutator surface. This is done with fine sandpaper, which is pulled under the brush which is being fitted; such pulling is to be in the direction of rotation of the armature, and the brush is to be pressed down firmly against the sandpaper, while the latter is held securely against the surface of the commutator, without fold or wrinkle.

Brushes can be used until they are quite short; sometimes they will give service if only three quarters of an inch of their original length is left.

Cleaning the Commutator

A simple cleaning of the commutator is effected by rubbing it with a cloth saturated with kerosene or machine oil. Occasionally it should be wiped with a piece of canvas lightly coated with sperm or machine oil. Lubrication should be used sparingly, as it interferes with good electric contact.

Motor and Generator Bearings

It is an all important thing to keep the bearings of a generator or of a motor oiled. There is a special necessity for this in such machines. The rotor, as the armature or it may be field, is called, the rotating member, has its periphery very close to the surface of the stationary part, or stator. If the bearings wear there is danger of the two parts coming in contact, and rubbing; this brings about destruction or injury at least, and oiling operates to prevent this wear. It is well to watch the machine with reference to the relative position of rotor and stator, to see if there is any change in their relative positions, which would tend to bring them into contact. If there is danger of this occurring immediate attention should be given to renewing or to shimming up the bearings.

How to do this cannot be told here, because it will be a different problem in every make of machine. The manufacturers of electric machinery are most anxious to have their machines work well, and will neglect nothing to bring about such a result. Accordingly not only do they take every care in building their machines but they issue bulletins, which describe their machines and tell just how to take care of them, and give special rules for each machine as far as such are needed.

Vertical Shaft Converters

Some machines of the motor generator type are made with vertical shaft. In this case the armature or rotor is set on end and turns in this position. This operates to save a great deal of floor space. It also makes it easy to remove the rotor, if such should be necessary, as it is pulled directly up out of the chamber in which it rotates. The arrangement has its disadvantages in one respect, that it does not provide for the to-and-fro motion of the armature to prevent the brushes wearing grooves in the commutator, if the machine is a direct current one.

Refusal of Motor to Start

The motor side of a converter is usually an alternating current motor. If when the switch is thrown so as to start it, closing the circuit, the machine refuses to start, it may be that a fuse is blown. The machine may be made for a three phase or other circuit, and the interpretation of its stoppage will depend on what circuit it is running on. Thus on a three phase circuit a machine may run with one fuse blown, but if stopped will not start until the fuse is replaced, if a single throw switch is used. If a double throw switch is used, the motor will start on the fused lines. It will not run properly, and its irregularity of action will show that a fuse is blown. There will probably be a noise due to the machine being out of balance, the motor will tend to heat a good deal, the speed will change if the load changes and there will be a tendency to unsteadiness of the arc supplied with current from the generator end of the machine.

The blown fuse should be replaced always; a machine should never be run with a blown fuse. A fuse is supposed to show by a blackening or stain of dark color, when it has blown. But owing to dirt this stain does not always appear. When the switch is thrown so as to give current the fuses may be tested, one by one, without removal from their sockets, by shortcircuiting each one by a lamp; if the lamp shows any amount of light the fuse is blown.

Sparking at Brushes

If there is considerable sparking at the brushes, the cause must be found and the remedy applies. Usually the remedy is simple; the trouble is to find the cause of the sparking. The General Electric Company gives the following statement of probable causes of this trouble.

Dirt on the commutator or brushes. Remove the brushes from their sockets and clean them on all sides, so that they will not stick in their sockets, but will be free to work up and down, as pressed by the springs against the commutator. If clean and free to work up and down a weak spring will be sufficient to hold a brush against the commutator, and this is what is desirable. A weekly cleaning of the brushes is recommended without removing the pigtails. The brushes must not be replaced in reverse positions. No copper should show on the rubbing face of the brushes.

Uneven wearing of the commutator. This may occur and may result in causing the mica to protrude; the English call this protrusion of the mica, "proud mica." Or the commutator may wear in grooves, running around it in the path of the brushes. To avoid the last trouble a slight end motion is generally allowed for the rotor or armature, so that the brushes do not follow the same path, but constantly change. Therefore if you notice a constant motion to right and to left of the armature, do not think that this is wrong; it is intentional. Elsewhere the removal of projecting mica is described.

Wrong spring pressure on the brushes. This is simple to fix; there should be enough pressure to make a good contact between brushes and segments of the commutator, and no more; also the brushes should work freely up and down in the holders.

Open circuit or short circuit in the armature windings. This trouble is generally to be found in the exposed part of the windings, where the wires are joined to the commutator segments; this is where they are likely to be bruised and damaged. A bolt or any other bit of metal or other material may get caught in the wires and strip them, or when the commutator is being cleaned and sand-papered a chip may fall in among the wires and do the harm. If it is an open circuit, the spark is so heavy, that it locates itself often by eating away the mica at the open circuit division. A short circuit in the windings will show itself by the heating of the short-circuited parts. These are troubles which should be attended to by an electrician.

Overload. This will cause sparking; the remedy is simple: Do not overload.

Brushes in wrong position. The brushes are supposed to be in the right position when the machine is received from the makers. There are marks on the brush yokes and on the bearing-housing; these should correspond and coincide.

REPAIRING ELECTRIC MACHINERY

Practical experience is required to make an electrician, so there is no difficulty in anyone determining their own capacity for repairing electrical machinery. The best rule to follow is not to undertake a repair unless you are competent. Harm may be done by incompetent treatment of troubles.

Send for an electrician. Be sure that he knows more about the technique of the apparatus and its operation than you do. He may know less. The electric light company can generally recommend a satisfactory man for repairs.

If a thoroughly competent electrician is called upon to repair your machinery, watch him, and you can learn a great deal, for the eyes are good teachers. If he is a good electrician he will be willing to tell you all about what he is doing, for it is only the poorly qualified, who object to imparting information. The attempt to make a secret of the work indicates an ignorant man; if an alleged electrician is secretive, do not trust his knowledge of the profession, for secrecy is one of the indications of incompetency. The more a man knows the more pleasure he takes in imparting his knowledge to others.

LAMP
HIGH
LOW
NEW YORK

POWER'S INDUCTOR

There is another thing to bear in mind; you cannot work without tools. Even in repairing bell wires in a house a voltmeter is a great assistance. How much more then is a voltmeter and other testing apparatus needed when an electrician is working around a comparitively high voltage circuit. This is where the regular electrician is apt to be ahead of the amateur of limited appliances if not of limited knowledge. The professional will have his portable testing set, and in his shop will have a lot more of serviceable things, which the operator of a projection machine cannot be expected to have at his command. But if the operator watches and studies the ways of handling troubles, he will sooner or later acquire apparatus and sooner or later will become his own electrician. And the more he advances the more will he appreciate his limitations and be more willing than ever to invoke the aid of the real professional in his troubles. The operator's part should be to keep the apparatus going in good order; his special knowledge should be expended in keeping everything in such shape, that repairs will be infrequent. He will be able to take care of minor troubles, but should take no risks.

HALLBERG ECONOMIZER

This is the trade name given to a specially constructed transformer, which is designed to regulate the alternating current supplied to arc projection lamps. This it does by reducing the voltage from that of the line, which may be 110 or more volts, to that required for proper operation of the arc, which may be put at 40 to

HIGH 60 AMP
LOW 40 AMP
HALLBERG

HALLBERG A. C. ELECTRIC ECONOMIZER

50 volts at the arc, although the voltage may be as low as 30 volts with careful management of the arc.

The apparatus consists of a rectangular core of laminated sheet iron. On it there are the two windings of the regular transformer, One is the primary and is designed to take the current from the service line. If there were only the one coil on the core the arrangement would set up a counter electromotive force and would act as a choke coil, opposing the voltage and cutting down the current to a very small fraction of what it would be with the line voltage, if there were no choke coil in circuit.

On the other side of the rectangular core, it may be, although the location of the coils may vary in different constructions, is the secondary coil. This is a coil of fewer turns and of heavier wire. Electromotive force is induced in it in general terms in proportion to the relation between the turns of the primary and secondary. If the primary has ten times as many turns as the secondary, the voltage in the secondary will be about one tenth that in the primary. This gives the general relation of voltages to winding turns in primary and secondary. The apparatus will operate only on an alternating current circuit and the secondary will deliver only an alternating current.

The cores with their windings are contained in a cylindrical case of perforated metal, so as to secure cooling, as the action of the alternating voltage on the core tends to heat it. On the top are two connections for the secondary. These are of a character to pass a relatively heavy current, and the projector lamp system is connected directly to these terminals. Four other terminals are provided also on the top of the case. These are for the primary circuit. The apparatus is a step-down transformer; it follows that when working at capacity, a stronger current will be taken by the secondary than that given by the primary. Were there no loss, if the transformer ran at 100 per cent efficiency, the products of current and voltage for primary and for secondary would be equal. While this is not the case, and while there is a loss, the current of the secondary is several times as great as that of the primary, and it is the strength of current which governs and determines the size of conductors. We may take these primary terminals as numbered, one to four. Number one is connected to the end of the primary coil. Terminal number four is connected to the other end of the primary winding. Numbers two and three are connected to intermediate points of the primary coil.

RANGE OF ACTION OF ECONOMIZER.

By this series of connections the economizer will operate for a range of voltage from 100 volts to 220 volts. Connection of the service line to terminals number 1 and 2 takes care of voltage of from 100 to 105 volts. It will be understood that terminal number one is never disturbed. Then terminals one and three take care of from 110 to 115 volts. If there is a line voltage of more than this, up to 210 volts, terminals one and four are connected to the line. There are several sizes made, and the above description applies to the smaller ones; the terminals used for different voltages are different from the above on the larger sizes such as are made for 220 volt lines.

There is nothing final about this adjustment of primary to secondary. An operator may have a 30 volt arc and the connections may be made, in accordance with what has been said, to give the proper voltage and consequently the proper amperage to the arc. But it may be that the operator wishes to have the power of forcing the illumination of the screen. A dark picture will exact more light for its projection than a light thin one will. For such cases a simple three-pole main line or primary coil cut-out is provided. It has three plug-sockets. By screwing a plug into one or the other of these sockets, the three various voltages, as just described are made to act on the primary, and the arc receives a heavier or lighter current accordingly.

LIMITATIONS OF TRANSFORMER.

The good point about the transformer type of regulating appliance is that it has no moving parts. Its whole action is electrical, and there is nothing to wear out. It does create some stray magnetic field. If the walls of the projection booth are of thin sheet steel, the transformer should not be placed too close to them, as it may cause them to vibrate and produce a noise.

What some would consider the bad point about appliances of this class is, that they necessarily supply alternating current, necessitating the use of an alternating current arc. The latter, it is fair to say, is not the favorite type of lamp. The secondary alternating current could be rectified by a mercury vapor of other rectifier, but every change of this sort involves loss of power, and is to be avoided if possible.

The motor generator gives direct current from an alternating current line, but it is not so simple as the transformer, and requires a certain amount of attention, for oiling and cleaning. The transformed needs practically no attention whatever, and no special knowledge. Too heavy a drain on the secondary might injure it, but this is not likely to occur, while a few minutes running with a dry bearing might seriously injure a motor-generator.

THE COMPENSARC

The compensarc is a motor generator; it is in some regards a pity that the trade name compensarc has been so definitely accepted, for every new word, in electric work, is a sort of misfortune, if it is not really required. Letting this go the characteristics of the Hallberg motor generator are of interest, because it is a machine built and designed for the special work required in projection. As the standard film is of comparatively short length, in the sense that it does not contain a story of any length, and as a new film has therefore to be inserted or put into action to complete the scenario, or to continue it, projection machines are generally run in pairs. The motor generator we are describing is built to take care of two lamps.

TWO TYPES OF COMPENSARCS.

There are two kinds of apparatus made. One converts alternating current to direct current; the other takes direct current at the line voltage and delivers current to the lamp circuit at the proper voltage to feed the arc, and this voltage is about half or a quarter of the line voltage. The idea of the D. C. to D. C. machine, as it is sometimes termed is to reduce voltage without the waste of power incident to the use of a rheostat. The A. C. to D. C. machine not only does the same thing but also delivers direct current, which is generally preferred for the arc light, so as to give a single crater in the positive carbon. The Hallberg compensarc is a typical machine of this class. The machines give on open circuit a voltage of approximately 180 volts. If a lamp is supplied with current the voltage drops to 60 volts. The circuit including two lamps is so laid out that the lamps are in series. When only one is burning the other one is short-circuited. This arrangement keeps the circuit closed although one lamp is inactive. The lamp, which is not burning can be allowed to cool, if it has been in use, and can have its carbons trimmed or replaced without disturbing the other lamp, if it is in use. If the lamp, which has been out of action is lighted by opening the short circuit in parallel with it, the voltage of the machine, which now has two lamps in series on its circuit, automatically rises to approximately 120 volts. The machine is so wound, that it accommodates itself to widely different requirements, as regards length of arc, and the supplying of current for one or two arcs. It gives the same current whether one very short arc or two long arcs in series are burning.

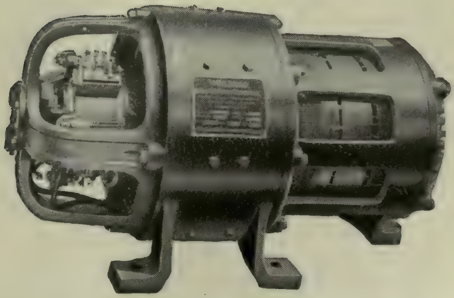
Installing the Compensarc

In installing the apparatus the machine may be placed at a distance from the booth. Its position is quite immaterial within reasonable limits. The switch-board or panel contains an ammeter and a field rheostat. This panel can be placed in the booth. For each lamp there is a short-circuiting switch, each of which is placed if desired on the stand of its picture machine. This is the logical place for them, so that the lamps can be turned on and off with the most convenience. The generator automatically protects itself from burning out and never makes an undue call upon the line fuses, so as to burn them out. Another point of construction is that the motor circuit and the generator circuit are entirely separate one from the other. The result of this is that the operator is protected in the booth from the voltage of the service line.

The direct current machine is closely coupled as far as its layout is concerned. It has two bearings only at the ends of its shaft. The alternating current machine is distinctively two machines in one; it has but one shaft but there are two armatures and two armature cores carried by the one shaft, and there is a third bearing between the two in the middle of the shaft.

HALLBERG
4 in 1
REGULATOR

HALLBERG MAZDA LAMP A. C. REGULATOR



HALLBERG COMPENSARC

Field Rheostat in Compensarc

The resistance of the field rheostat can be changed so as to give a wide range of current.

To start operations one lamp may be lighted, its arc being struck in the usual manner. The other lamp has its short circuit closed so as to be out of action. This is done by the short-circuiting switch. To start the second lamp for the change-over, its carbons are brought together until they touch, the short-circuiting switch is opened and the arc is struck. The first arc has now to be extinguished. To do this its carbons are gradually brought together and the short-circuiting switch is closed, thus taking current away from the arc.

The higher first cost of these machines, as compared with the simpler appliances, either rheostat or transformer, limits their use to a certain extent. But the economy and other advantages incident to their use is so great, that there is every inducement for their adoption if possible.

The rheostat is wasteful of energy. The transformer is not so, but gives an alternating current, which is not the best for the arc lamp. The rheostat also is sometimes a disagreeable neighbor on account of the heat it generates. The disposing of all these troubles is what constitutes the merit of the motor-generator in this field of work.

One of the illustrations shows the arrangement of the field rheostat directly behind the panel carrying the amater and the handle for varying the resistance of the same rheostat.

Self-Adjustment of Compensarc

The automatic adjustment of the machines to the change over is effected without flicker or noise, and the self-protection of the machines is such that they will not burn out, even if the carbons of a lamp are brought in contact with each other, so as to cut down the resistance to a low figure. They require it is claimed no ballast or steadying resistance. If such is put into the circuit it may be so slight as not to involve any great loss in power, due to its resistance.

The Three Windings of the Compensarc

There are three separate and distinct windings on the field cores of this machine. On the field core there is first the shunt winding. This is in parallel with the winding of the armature, and is composed of fine wire wound in many turns, with one of its ends connected to the brushes on the brush rigging of the commutator. The first effect of this parallelism of field and armature is that if there is lowering of resistance bringing a draught of current upon the armature, the shunt winding of the field gets less current than it would otherwise. Thus a lowering of resistance in the outer circuit goes to reduce the strength of field of the generator and thereby to reduce the electromotive force induced in the armature windings. To enable the operator to vary the strength of the field a small rheostat is placed in circuit with the shunt winding, which rheostat is controlled from a switchboard.

The other end of the shunt winding is carried out as a separate terminal of the machine.

There is another field winding, put on top of the shunt winding, and in series with the shunt coils. It is composed of a few turns of thick wire, and is in series with the armature windings; it is called the compound winding. Its terminals also come out from the machine, so that it can be connected in two different ways. In ordinary machines the compound winding is permanently connected, so as to act along with the shunt winding to keep the voltage up. In the Hallberg machine it is susceptible of two different connections. These terminals come out through the frame of the apparatus, and are connected differently in case one or two arcs are to be connected in parallel or if the two arcs are to be worked in series. If only one arc is to be supplied the compound winding is connected in series with the armature winding and in such relation as to be in opposition to the shunt winding. The current in the compound coils then "bucks" or opposes that in the shunt coil. This arrangement operates to cut down the current by reducing the electromotive force. The current in the compound coils flows in the opposite direction to that in the shunt coils, and the voltage is cut down to thirty-five volts, enough for one arc or for two if in parallel. Of course as long as the arcs are in parallel, the voltage for one would be enough for any number. The machine is not large enough to give current to an indefinite number of arc lamps. The amperes deliverable by the generator regulate that.

CONSTANT CURRENT FROM COMPENSARC

When the compound winding is thus connected so as to buck the shunt winding, the generator delivers a practically constant current at variable voltage as may be required, so that the arc is under regulation and control without any external resistance for ballast. Any desired current can be given the arcs by the use of the field rheostat. Two arcs may with this connection be operated in parallel. If the generator is of large enough size and capacity more than two arcs can be maintained. They must be in parallel with one another, and as their resistances vary, the generator automatically takes care of the changes, and gives the arcs the same current, whatever the variations in their resistances may be.

OPERATING TWO LAMPS WITH COMPENSARC

If two lamps are arranged in parallel, and one is burning the second one can be started by bringing the carbons together. As an arc is struck in the second lamp, the current is taken away from the first lamp, which has been burning. The arc goes out, and the lamp just started takes up the work and continues the burning. The operation is called "stealing the arc," and with practice can be done so that the audience will hardly notice any change. The hot carbon ends of the extinguished lamp prolong its light for enough time to help the change.

INCREASING VOLTAGE ON COMPENSARC

If the voltage is to be brought up to 70 volts, enough for two arcs in series, the connections of the field windings are so connected that the compound windings and the shunt winding work in unison, and this brings up the electromotive force to double the preceding voltage.

WINDING OF COMPENSARC

The current in the compound field winding is controlled as regards direction by a double switch. If the switch is thrown in one direction the generator is a constant current one; if the switch is thrown in the other direction the machine becomes a constant potential one. If it is the latter, the voltage is of the double value, 70 volts. As it no longer is a constant current generator and as the lamps vary in resistance a ballast resistance is required to operate the system. There is one provided accordingly, which is thrown into the circuit by the same switch at the one motion.

On the larger machines there is a third field winding carried on separate pole pieces between the regular poles. The winding consists of wire of large caliber connected in series with the negative lead from the armature. This is called interpole winding, and its purpose is to assist the commutation of the current and to prevent sparking at the brushes. This part of the winding does not interest the operator, unless it becomes partly short circuited or cut out. If this happens sparking will take place at one or more of the brushes. This will discolor the commutator surface, and this discoloration will show that something is wrong. It is, however, quite possible that sparking will occur, discoloring the commutator, without the interpole winding being at fault. The discoloration does not indicate trouble with the interpole winding necessarily. It merely points that way.

Durability of Compensarc

If not abused, if kept properly lubricated, and if not tampered with in the way of improving its running, the machine will last for years. There is no strain to be resisted, the only wear is that of the shaft journals, for electricity does its work without mechanical wear and tear. If anything seems wrong with the apparatus, write to the manufacturers; their object is to maintain the reputation of their product, and repairs and adjustments by those not familiar with the machine is one way to impair its operation and to bring about a breakdown. The rule for the operator should be, to do as little as possible as long as the machine does its work.

CHAPTER V

EXTEMPORIZED RESISTANCE

THE rheostat is the regulation resistance for taking care of too high voltage on the supply line. Its action depends on its regulating the flow of current as the arc varies in resistance, by its own resistance varying inversely with that of the arc, and thus introducing an automatic factor of action, all which has been explained. There are other ways of introducing resistance than that of the metal rheostat, and some of these are of interest even if seldom used.

A bank of incandescent lamps is a simple appliance for building up resistance. It is often used in other functions than for regulating the current for projection of pictures. It is a method, which gives a very impressive presentation of the wastefulness of the resistance system of controlling current. The lamps are used by being arranged in parallel so as to be of the proper resistance to cut down the current to the requisite amount. Thus arranged they operate by being thrown into the circuit and at once start to burn with a more or less bright light. This is the demonstration, for a bank of lamps cannot be lighted free of expense.

In some cases they may not be given current enough to show any light; then the demonstration is not to be seen.

A 100 watt 110 volt lamp passes about .9 ampere of current. Its resistance is about 120 ohms. To get a thirty ampere current for a small arc lamp would require a bank of about thirty-three lamps in parallel. This would make quite a display if they were lighted at full voltage, and if such a resistance were used for a larger arc light, it will be seen that a great amount of light would go to waste, unless something could be done to utilize it. Mr. J. H. Hallberg, in his very interesting book on Motion Picture Electricity says that proposals have been made to utilize such light, but the methods are not very practical. If it could be practically done this would be the best kind of a resistance. As it now is, with the lamps burning out, slowly it may be but surely, it is about the worst of all resistances, and its use is only to be recognized or authorized under definite conditions of urgency. In incandescent lamps the engineer has ready-made units of known resistance at his call, and situations may arise when they will be invaluable. In small experimental work they are often used to great advantage, but in such cases the amount of current is so small, that the question of economy does not come up for consideration.

One very bad feature is, that in striking an arc, so high a voltage may be thrown upon the lamps, as to cause some of them to burn out. This applies to the case when low resistance lamps are used on a high resistance circuit, relatively speaking, and when the resistance of the arc is relied on to protect the lamps.

The Water Resistance

A water resistance is a form of rheostat, which has been used a great deal for many purposes, but probably so little for projection lamps as to be quite exceptional for them. But it is simple and positive, and it might sometimes extricate an exhibitor from a difficulty. It is a safe and powerful resistance, which can be extemporized in a few minutes from the commonest materials. A barrel is often the basis of its construction. One terminal of the circuit is connected to a plate of iron or copper by a rubber covered cable and the plate is laid in the barrel, resting flat on its bottom. A second plate faces this one and is suspended over it in the barrel by some simple arrangement, so that the distance between the plates can be changed. The barrel is charged with enough salt water to immerse the plates. The saltier the water the less will its resistance be, and the nearer the plates are to each other the less will the resistance be also. This is the water rheostat, and it is susceptible of endless modification as regards the vessel used, its size and capacity. It is quite conceivable that it might rescue an exhibition from serious trouble where unexpected conditions of voltage on the service line were encountered. Anyone can make one, and it is the safest of all resistances, as the water protects the system from fire. A metal-resistance rheostat may rise to red heat; this one gets quite hot, but it is the heat of boiling water or a shade more under extreme circumstances. Such heat can do no harm.

Storage Battery Resistance

There is another way of constructing a sort of rheostat or a reactance, if the expression may be used for this case. This arrangement is a storage battery set up in opposition to the voltage of the circuit. It is not an improved rheostat, as it operates not by resistance, but by counterelectromotive force, bucking the current in the supply line.

Suppose we have a 110 volt circuit as the supply for a fifty volt arc lamp. The lamp may be assumed to require a current of thirty amperes to operate. If it were a case of a rheostat, we should go on the basis of resistance in our calculations, but the resistance of a storage battery is so low that we may neglect it virtually. The problem may be taken as one of voltage. Each cell or storage battery takes up about two and a quarter volts in counter electromotive force. Therefore to get the 110 volts reduced to 50 volts for the lamp, 60 volts must be absorbed by the storage battery. Sixty divided by 2¼ (the latter the voltage of a single cell) gives 26⅔ cells to develop this voltage in opposition to that of the line. The lamp requires 30 amperes; the battery therefore must be given a charging current of this amount, when the lamp is in action. This gives the datum for the size of the battery cell. It must be large enough to take this current. Then a ballast resistance will be needed in series with lamp and battery. To compensate for this we must reduce the battery one or two cells. Twenty-five or perhaps twenty-four cells would be enough for the case assumed.

On its face this arrangement is as uneconomical as a rheostat, and is inferior to it in its action, because it has no ballasting effect whatever. It is even necessary to introduce a ballasting resistance as we have just seen. There is a certain economy in it. The charged battery will give power when called on, and in that way will pay back part of the power which is expended upon it. This saving or return is put by J. H. Hallberg at about fifty or sixty per cent. of what it receives. If this can be used advantageously, the method is superior on such a showing to the use of a rheostat. But a storage battery is expensive in first cost, is somewhat troublesome to take care of, and deteriorates, though it may be very slowly. There is one possibility, which presents itself. The battery might be used part of the time as a source of power for the lamp. Thus it might be used at the beginning of an exhibition, and the lamps, both of the projection machine and of the building could be supplied by it. The voltmeter would tell when exhaustion was approaching. When the reading of the instrument ran down to perhaps two volts per cell, the power-switch could be thrown so as to draw from the line and restore the battery to its strength. The suggestion is given for what it is worth. Unless something of the sort can be carried out, it is hard to see where the benefit of this use of a storage battery would come in.

Storage Batteries and Ventilation

There is apt to be trouble in the ventilation of a room containing a large storage battery. The battery is constantly gassing, (evolving hydrogen) while it is overcharged and receiving current. This will often be the case in the use described. The bubbles of hydrogen carry into the air a minute spray of sulphuric acid, which is intolerable to the respiratory organs, if it is of any considerable amount. It has a tendency to corrode anything of metal it can get at. So if a storage battery is to be used provisions for avoiding this trouble must be seen to.

Ground Connections

The earth acts like a conductor of zero resistance. It is probable that if a good enough connection between circuit and ground could be established, the return circuit of the earth for a current would be of negligible resistance.

In the case of a full metallic circuit the current goes the full length of the circuit by the path of the continuous conductors. On a ground return circuit the current goes one way through the wire and completes the circuit by the earth. Each end of the line in such case is grounded, and the current as far as we know goes through the earth on one-half of its course. By the use of the ground circuit one lead of wire is saved; it was one of the most important discoveries in telegraphy.

To get a ground connection it is a frequent practice to solder the wire to be grounded to a water or to a gas pipe. This gives a very good ground; it is a question how much is ground return and how much is done by the metal of the pipe. Electric car lines use such heavy currents that they do not rely on the earth for a return, but utilize the rails. These are not insulated; if current leaks into the ground it does no harm as far as loss of power is concerned. The lines overhead are insulated, and that is enough, the rails and earth combined can take care of the return of the current. But the system is said to be grounded through its rails. On an automobile the frame or chassis of the car is generally used to carry the current in one part of its circuit; in this case the metal of the car is said to ground the circuit.

ELECTRIC GROUNDS

When an electric ground is spoken of, it is not always the true ground, that is meant. If a part of the wire carrying current to the lamps in the projection room comes in metallic contact with the steel walls or frame of the structure, the connection thus made is called a ground.

ACCIDENTAL GROUNDS

When one ground is made no harm is done until a second one on the same circuit is made. If this occurs a return path for the current is created and a low resistance path for the current may be opened. A ground always involves the possibility of trouble. In electric light practice it is the custom to ground certain parts of the system. In this there is a certain risk involved, although the practice is approved of.

The operator must take the utmost care to avoid the formation of grounds on his system of conductors. The steel of the projection house and the metal frame of the lamp give excellent chances for the making of bad grounds. The existence of a ground will not be revealed until a second ground is made and then there may be a heavy current started, the lamp may be affected and various troubles may result.

LOCATING GROUNDS

The lines of wire supplying a small one-lantern or two-lantern house are so short and simple in their course that a ground can be searched for by inspection alone. But as lanterns in one plant increase in number, the complexity of the wiring increases until grounds can hardly be detected with any degree of certainty by inspection. They have to be searched for with a test lamp or other indicator. A voltmeter is a good instrument to use. The trouble with it is that it gives no clue to whether an indication of voltage given by it is due to a bad ground or to a trivial leak, not enough to constitute a full ground. An ammeter will give the strength of the current and will disclose the seriousness of the ground, but there is a possibility of the ammeter being burned out if there is a bad ground. A lamp for the circuit voltage will answer the purpose, but a slight ground might exist, which would not show in its filament, because enough current to make the filament luminous might not be able to pass the ground; a lamp and ammeter in series may conveniently be used.

Grounds in Lamphouse

The carbons and all their connections are insulated from the frame of the lamp, by mica washers and bushings or similar fireproof insulation. A ground may be made by the mica failing in some place and permitting the metal of the carbon holders or of their connections to make a connection with the frame of the lamp. If such a contact exists, the whole projection room will be connected to the circuit, it will form a ground for the carbon holder, and for the wire conductor leading to it.

If there is no break in the circuit, the only opening in it will be formed by the arc gap, and if it is opened by the switch. To try for a ground the switch must first be closed, but the arc must not be started. This is the condition for testing for a ground.

If a lamp or other indicator is now connected at one terminal to the frame of the lamp or to any convenient part of the metal work of the projection house, the other terminal can be used to explore with for the suspected or possible ground.

It is assumed that the operator is certain that the lighting circuit is unbroken. This can be tested for by bringing the carbons of the lamp into contact with each other and seeing if they get hot, so as to be in a condition to start an arc. Some direct the testing with the test lamp for continuity of circuit. This is done by connecting the carbons to the leads from the two terminals of the lamp, and seeing if the lamp lights. If it does the circuit is continuous and unbroken.

Testing Lamp for Grounds

The circuit having proved to be intact and the testing lamp being connected to the metal frame of the lamp or to the steel of the projection house, the other end of the lamp terminals is touched to one of the carbons. If the other carbon or its conducting lead is grounded current will pass through the lamp. The testing of the lamp has shown that the current is intact as far as supply goes. Therefore the ignition of the testing lamp will take place if the carbon to which it is not connected is grounded.

If a rough sketch be made of the connections as described, it will be seen that, in the condition of a ground existing, the lamp used for testing will short circuit the arc gap between the carbons. It will be lighted as it would be if there were no ground and it were connected across between the arc gap.

A ground on either side of the lamp will be revealed by two trials at the most, one for each carbon.

Now suppose that ground has been found to exist on one of the lines of wire entering the place. The grounds may be quite far back, and not in the projection house. The lamp may be used to locate the place.

Keeping it grounded on one of its terminals the other terminal is used to explore with. It is held against the frame of the lamp. It will light on account of the ground. Open the grounded line at any convenient point. This will be where there is a switch. The other line must be kept closed. If it is a double throw switch a bit of wire must be used to close the other side of the switch.

With a piece of wire ground the line back of the switch. Opening the switch will have put out the lamp, unless there are several grounds on the one line. If grounding the supply line back of the open switch, with the lamp connected to the lamp frame, lights the test lamp, there is a ground between the switch and the grounded carbon. If the lamp does not light, then the ground is back of the switch. The switch must now be closed and another break or opening in the same lead must be made further back. The line back of the last break is grounded. The test lamp will light if the ground lies between the first and second breaks in the line.

In this way the line can be tested and the break located by the test lamp.

Finding Grounds by Inspection

It is not always advisable to go at the testing operation in this way. It is often easy to find the ground by simple inspection. In the case of a projection house there may be only a few short leads, on which the ground could occur. In such case a ground can be found without much trouble, by looking for it, following the lead of wire until it is discovered.

GROUNDS IN A RHEOSTAT

To test out a rheostat when disconnected from the circuit, it is necessary to have some source of current, such as a hand generator or a battery. The usual apparatus for this work is a bell ringing set. This is connected across the terminals of the rheostat and the handle turned. If the rheostat has no break the bell will ring. A silent bell indicates that there is a break in the rheostat conductors.

If there is no open circuit on the rheostat try to ring the bell, when connected from one of the coils to the metal frame. A ring will show a ground, in this case a connection between the coils and metal frame of the rheostat. As the coils are all in circuit with one another, the ringing will not tell where the ground is. To find this out, each coil must be tested for a ground, first being disconnected from the other coil or coils back of it. Testing the coils one by one will locate the ground in one of them. When a coil is reached at which no ringing is produced, this coil and all those which follow it are free from grounds. The coil preceding it is the grounded one.

RESISTANCE IN VOLTAIC ARC

The voltaic arc, which is produced between the points of the carbons of a projection lamp is a conductor. There is nothing special about the projection lamp arc, as far as its general properties are concerned, but in common with all voltaic arcs it has one feature, which is the cause of considerable inefficiency and of a certain amount of trouble. Its resistance diminishes as it gets hotter. Suppose now that an arc lamp were connected across the leads of an electric system, and that current was started through it. As the carbons became hot and as they were separated, and the arc formed, heat would be produced. The resistance would fall and more current would pass. The heat then would increase still more, and more current would pass. Thus heat and current would both increase together and where it would stop would be hard to tell, if there were no resistance except that of the arc.

COUNTERACTION OF CIRCUIT RESISTANCES

But there always is other resistance, that of the wires and connections. As these get hot their resistance increases. This operates to control the arc, whose resistance operates in the inverse way. But the arc cannot be regulated by the slight resistance of the heavy copper wires conducting the current of the lamp, and the resistance of the connections is not enough for this regulation. Accordingly a considerable resistance is put into the lamp circuit, and this apparatus containing the resistance for steadying the lamp is called a rheostat.

It operates exactly as we have described the action of a conductor, its resistance increases as more current starts to pass, and diminishes as less passes.

To regulate the action of an arc lamp a rheostat of about the resistance of the arc is needed. Hence it follows that in a lamp circuit with arc lamp and rheostat about half the power is wasted.

CARE OF THE ARC LAMP

The arc lamp is subjected to special causes of dust, and an accumulation of dust operates to interfere to a greater or less extent with its perfect working. There is a certain amount of carbon dust to be apprehended, and the situation of the lamp in the little projection room is not favorable to cleanliness. The same is indeed to be said for the whole projection apparatus. But the lamp in the lamphouse gets the benefit of any dust, which the arc may produce.

If the lamp is allowed to become perfectly dry it will not operate well. The operation of a lamp means the regulation of a voltaic arc less than half an inch between carbons. This all important distance it is, which affects the results of the lamp. It will be brighter or darker, will burn steadily or will flicker, will give a crater properly or improperly placed, according to the length of the arc. It is evident that the carbons must be susceptible of the most exact regulation by the operator or by automatic feed supplemented by the hand of the projectionist.

Once a week a lubricant should be sparingly applied to moving parts, such as threaded adjusting gears, racks, sleeve rollers and the like. Too much of the lubricant should not be used; the great point is to neglect no part of the machinery of the feeding and adjusting parts, yet not to clog it with grease. Special lubricants are made for use in projection arc lamps.

Quality of Lubricant for Arc Lamp

The conditions are more or less trying to a lubricant; be sure to employ a lubricant obtained from a reliable projection machinery house. Do not rely on what may be said in a hardware store or in a garage.

Do not let the lubricant get on the mica insulation; this must be kept dry and free from oil and the like.

Contacts in Arc Lamp

As far as possible the resistance of the lamp should be concentrated in the arc. It follows that the connections between the carbons and their metal holders should be good electrically. The metal at these places should be scraped and cleaned at least once a week. The point is that carbon and metal should be in perfect contact one with the other. If the contacts between carbons and the metal holders are bad, it will produce heat, possibly enough for the trouble to be recognized by the temperature of the metal in the vicinity of the contacts. The heat will be relatively high; in any unusual degree of heat it is that this trouble may disclose itself.

The contact of the wire with the binding posts should be looked after. The current taken by an arc lamp is not very large, and no unnecessary resistance should be put in its path.

Replacing Lugs in Arc Lamp Connections

The terminal lugs will deteriorate under the effect of the heat and will eventually increase in resistance. They should be thrown away before they are too far gone. The wires inside the lamp house are supposed to deteriorate, and to lose conductivity owing to the service they are called upon to perform. The heat of the lamphouse is supposed to burn them out, "to take the life out of them." It is then time to cut off and throw away the burned portion, so as to have good metal up to the binding posts. If wires are left too long in service inside the lamphouse, there is danger that they will deteriorate until they practically burn off and part.

ARC AND INCANDESCENT LAMPS

The ideal light for projection of pictures would be a luminous point. About the nearest approach to such is the luminous crater of the D. C. voltaic arc. Very remarkable results have been attained in its development in the Sperry search light. The arc light is, as far as quality of light goes, the best illuminant for the moving picture projector for large pictures on the screen.

The voltaic arc is produced by a current of electricity, which passes through the space between the ends of the two carbons of the lamp. It will not start through the air. The smallest separation of the carbons shuts off the current completely if no arc has formed. The arc has to be started by what is called "striking."

RESISTANCE OF HOT CARBONS

Carbon, of the kind used in electric light carbons, is a fairly good conductor of electricity. To start the arc or to "strike" it, the ends of the carbon pencils of the lamp are brought together, so as to touch. At once a current starts, the circuit being closed. The point of contact of the carbon ends is of comparatively high resistance, and begins at once to get hot. Now as the carbons are drawn apart the voltaic arc forms. The heat concentrated at the point of highest resistance is enough to volatilize a trace of carbon, which forms a path for the current through the space between the two carbon ends. The heat rapidly increases, the resistance of the arc decreases as its heat rises in degree, and more and more current passes, and thus the arc is established.

A voltaic arc has to be operated on the reverse lines followed and required for operating an incandescent lamp. If the latter has its terminals connected to a circuit, in which there will be maintained a constant potential difference between the terminals of the bulb, the lamp will burn with perfect steadiness. As it gets hotter it increases in resistance; thus if the current tends to increase the corresponding increase in resistance cuts it down.

Incandescent Lamp for Projecting

The incandescent lamp works on a constant potential circuit, and for such is self-regulating. Too great a potential will burn it out, as it is termed; but if it is supplied with the proper potential it will average its usual duration of burning.

The case is the reverse with the arc lamp. As its resistance falls with increase of temperature, the hotter it gets the more current will pass if a constant potential is kept up. To make it give a uniform light, it must be supplied with a constant current; a constant potential, unless means are taken to keep the current constant, is fatal to its operation.

Hence it is that when an arc lamp is connected in a constant potential circuit, a resistance or some current regulating appliance has to be put in series with it.

The incandescent lamp is used in greater proportion all over the country each year. In the old days, the carbon filament lamp, whose rather feebly glowing filament was ironically compared to a red hot hairpin, was a very poor and uneconomical burner. It was of very low efficiency, and its light varied in undue proportion to the voltage. A slight fall in the potential of the circuit cut the light down a great deal. The carbon filament lamp used to be assumed to give one candle power for three and a half watts of power. As there are seven hundred and forty-six watts to the horse power, this gives pretty closely two hundred candles watts or more to the candle power.

It did not always do as well as this; it often ran down to four watts or more to the candle power.

But now after long waiting we have the successful metallic filament incandescent lamp so that there is another state of things. The tungsten filament lamp gives a far higher efficiency than did the old carbon filament one.

Efficiency of Incandescent Lamp

The efficiency of any illuminant depending on an ignited substance for its light giving powers, increases as the temperature of its operating increases. The temperature to which the tungsten filament can be raised, in the bulb containing it, is greater if the bulb contains nitrogen or argon gas, than if a vacuum is produced in it. Too high ignition affects the tungsten largely by causing the metal to volatilize. The temperature of volatilization is raised materially by the pressure of the inert gas, argon or nitrogen in the bulb.

GAS-FILLED LAMPS

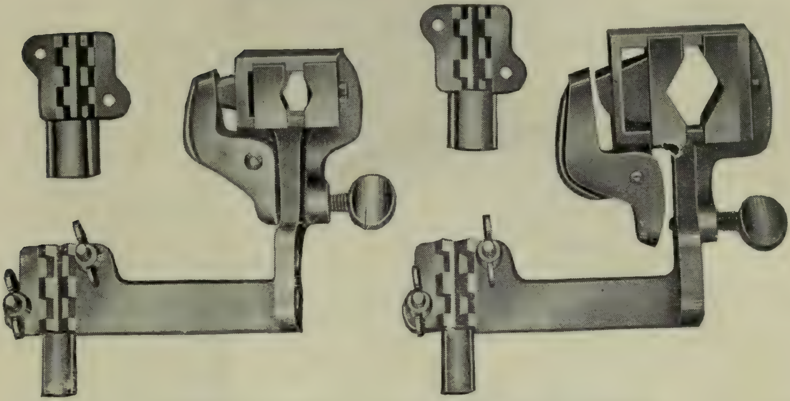
The effect is that in a gas-filled bulb the temperature of a tungsten filament can be raised to a temperature so high, that less than a watt will be required to develop one candle power. This brings the efficiency of the incandescent lamp to three or four times its former figure.

Better than this is attained by it under favorable conditions even as high an efficiency, as half a watt to the candle power, being claimed for it sometimes.

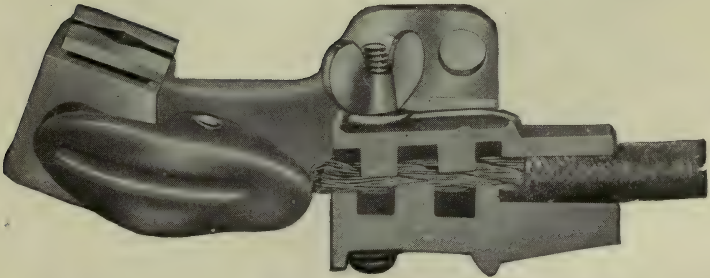
More will be said about the tungsten lamp elsewhere; it is clear that there is a reason why the arc lamp is going to be less and less used, and why it is being replaced by the incandescent lamp even in the projection field.

The public service circuits are always constant potential circuits and hence are the wrong kind for arc lamps. The projectors, however, as a rule have to rely on the local circuits for their supply, and if they use arc lights in their projectors, have to cope with the difficulty as described.

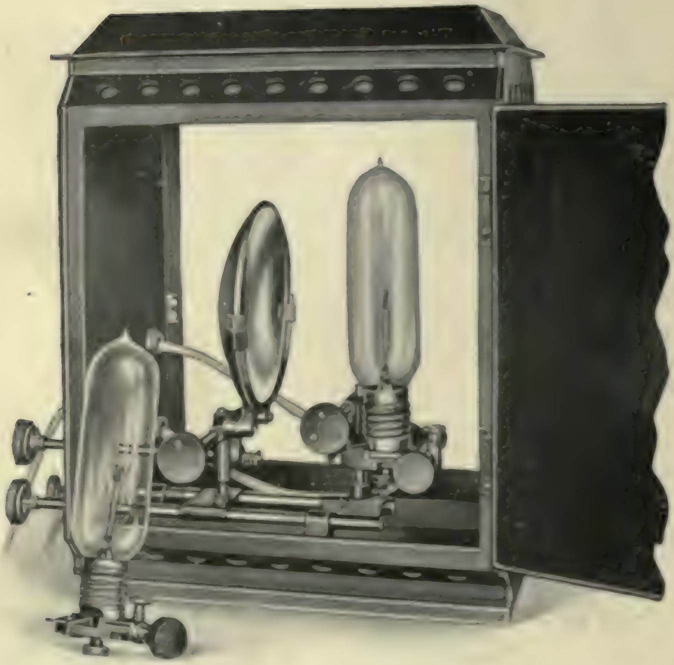
To obtain a constant current without any special appliance, arc lamps should be connected in series and whenever they are operated without a rheostat or other controlling apparatus they are thus connected. Sometimes arc lamps for street lighting have been connected and operated on constant potential, but with the same disadvantage encountered in their operation by the operators of arc light projection apparatus.



CARBON HOLDERS AND LUGS FOR ARC LAMPS



CROSS SECTION OF POWER'S CARBON-HOLDER SHOWING POSITION OF WIRE IN INTER-LOCKING CORRUGATION



SIMPLEX MAZDA LAMP EQUIPMENT

CHAPTER VI

Light Waves, Beams and Rays

LIGHT is theoretically taken as a system of waves in the ether. As a matter of convenience we speak of rays of light and of beams of light, although there is no such thing as beam or ray. Light travels through space in straight lines, never in curves. By Einstein's theory it may be deflected from its straight course by gravitation exercised by a sufficiently large celestial body, such as the sun. But this for all practical purposes is nothing, and we have to treat light as traveling in perfectly straight lines.

When we say lines we mean "direction"; just as there are really no rays or beams, there are no lines. It is one movement filling the space where it is active with a general distribution of light. But for convenience of expression rays, beams and lines are spoken of, although they have no real existence.

Reflection and Refraction of Light

Light may be deflected from its straight line of travel by reflection or by refraction. A looking-glass will reflect light in any direction. But the path in which it travels continues to be a straight one. The reflection simply changes its direction, but it takes the new direction, and goes on in a straight line of progress.

We are familiar with light in two variations; one is in parallel rays or distribution, the other is in radiating rays.

Light from the sun is really converging, because the sun is about ten times the diameter of the earth. But our great luminary is so far removed from us, that the light we receive from it is practically parallel.

Artificial Sources of Light

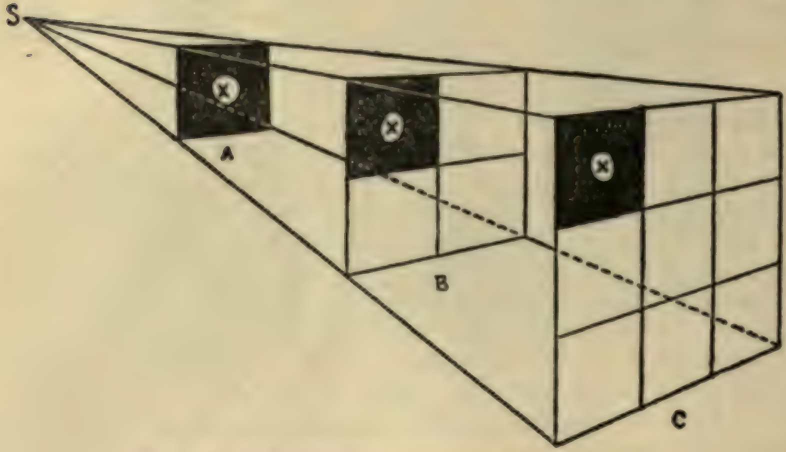
Artificial light, candle, oil, or electricity or any other kind is distributed from what is almost a point, and which is so small in area that the rays diverge. Artificial light is always diverging or radiating.

If the hand is held up in the sunlight, so that its shadow is cast upon a wall or other surface, the shadow will be exactly the size of the hand. But if the hand is held so as to cast a shadow in the light of a lamp or other artificial light, the shadow will be larger than the hand. This is because the rays of light from the source of artificial light diverge, on account of the small size of the light-giving surface, and on account of its nearness.

LAW OF THE INVERSE SQUARES

It is this feature of artificial light that leads to the enunciation of what is known as the law of the inverse squares. This law as stated is to the effect that the intensity of light varies inversely as the square of the distance.

This means that if a light is of a given intensity at a given distance, it will be of one-fourth that intensity at twice the distance, of one-ninth the original intensity at three times the distance, and so on for all distances; to get the intensity the distance must be multiplied by itself, and made the denominator of a fraction with the numerator one, to express the relative light at any distance.



LAW OF THE INVERSE SQUARE ILLUSTRATED

The diagram is the one used to illustrate this law. It will be seen that the light at twice the distance from its source covers four times the original area, that at three times it covers nine times such area; therefore it follows that at these distances it must be one-fourth and one-ninth as strong as at the first distance.

There are two things to be noted here. The law is always stated as if it were a general and universal one; it really only applies to a special case, where light radiates from a point.

The light from the sun or the light from the moon is not subject to this law, because there is no radiation in diverging paths or rays in the case of either of these luminaries, as far as we are concerned. Next take the case of a large bonfire. Here again the law would not hold because of the large area of the light-giving surface of the fire. It is only at a considerable distance that the law would be even approximately true.

It does not hold well in the case of the mercury vapor arc lamp, where a large area of luminous surface is the illuminating agent; the rays are not evenly divergent.

It is evident that the law of the inverse squares expresses a condition, which is special not general. It applies only to light emanating from a point. It happens that all artificial sources of light are luminous points or nearly so; hence it is that the law is taken as applying to all artificial light, provided it comes from a single lamp or source.

Practical Realization of the Law of the Inverse Squares

To obtain a practical realization of what this law means, light a single lamp in a room with dark walls. The darker the better. It will be astonishing how little light it seems to give. If you can read in comfort three feet from it, at six feet you will receive only one-fourth the light. The effect is almost as if all the lamp did was to make a hole in the darkness. It follows that for living and every-day purposes we should get rid of the law we are speaking of.

There are several ways of doing this. One is by using more lights, distributed about the room. A number of wall brackets are efficacious in this respect. A large number of burners on a branching chandelier are also conducive to a more even illumination. But practically speaking, the best method of distributing light is by reflection from the walls and ceiling of the apartment. It is getting to be considered good practice to paint the walls of factories white, to obtain this reflection; barreled sunlight it is sometimes called.

INVERSE SQUARE LAW IN PROJECTION

In projection there is a source of light represented by the opening in the slide carrier or in the gate of the moving picture projection apparatus; from this restricted area the light passes through the objective and falls on the screen. The area of the picture on the screen is so much larger than that of the lantern slide or film picture, that the law of the inverse squares applies with quite close approximation to truth.

THE THROW OF THE PROJECTION

The same objective with a smaller throw, will give a picture more brilliant approximately in the ratio of the inverse squares of the distance of the screen.

Suppose the screen was one hundred feet from the objective lens. It would have a certain brilliancy. Now let it be moved to a distance of seventy-five feet from the screen. These distances are as one is to three-quarters, or 1 : 3/4. The light received will be in the ratio of the inverse squares, which is the square of three-quarters or nine-sixteenths to one, 9/16 : 1. The picture at the distance of one hundred feet will have only nine-sixteenths the brilliancy it has at seventy-five feet.

It is all a question of geometry, the length of throw has no direct influence upon the brightness of a projection, unless the air is obscured by smoke for instance. If the air is pure in the theatre, the length of throw only affects the brightness of the picture on the screen, by its effect on its size. The smaller the throw the smaller the projected picture will be and the brighter. The area of the picture and consequently its brightness will both vary in accordance with this law.

A beam of light composed of parallel rays is very little affected by the distance it may have to travel. Practically all that affects it is the obscuring elements in the air, such as smoke, fog, mist and the like. For this reason the light of a searchlight can be seen for a great distance because it is composed of parallel rays, brought into parallelism by the reflector of the lamp.

RELATION OF THROW TO BRIGHTNESS OF IMAGE ON SCREEN

The departure of projected pictures from the law of the inverse squares is due to the fact that on moving the projection apparatus nearer or farther from the screen, the projected picture varies in size in a different ratio than would be given if it always followed the cone of rays from the lamp determined by one position of the screen.

To get the practical figure of how much the light of a projection is affected by distance, we must know the size of the area of the screen covered by each of the two projections we are comparing; the brightness of each picture will vary inversely as the areas.

Suppose that one picture when projected is nine feet high and twelve feet wide, giving an area of one hundred and eight square feet. Suppose that the other projection is twelve by sixteen feet, an area of one hundred and ninety-two square feet. Then the relative brightness of the large picture to the small is as 108 to 192, which is as 1 to 1 7/9; the small picture is nearly twice as bright as the large.

If the air of the theatre is clear the relative brightness will be unaffected by the length of throw. If the air is full of smoke the projection at longer throw will be most affected by reduction of brightness.

Of course the throw under all ordinary conditions is never changed. The law of the inverse squares may have little practical importance in every-day work. But it is an elementary law of optics, and is not so generally understood as it should be. Especially should it be understood for the reason that the effect of this law is confused with the supposed effect of length of throw. It should be realized that the length of throw has little or nothing to do directly with the brightness of a projection, except in cases where the air of the theatre is obscured by smoke or other cause. But simple distance has comparatively little effect on the transmission of light.

Relation of Size of Image to Brightness

A projection of twice the diameter of another one will have only one-quarter the brightness; a good rule in planning the size of projections is to keep them small enough to be bright; a small increase in diameter reduces the brightness to a very great extent.

As the relation of width to height is the same whatever the size of the projections may be, to calculate the relative brightness, it is enough to square the heights or the widths and to use those figures for the proportion.

In the example given above we could have used the squares of the heights, 81 and 144. These are the squares of the heights of the two projections, of nine feet and of twelve feet, and their inverse ratio is 1 to 1 7/9 just as before. The ratio is obtained by dividing 144 by 81, and giving the larger value to the smaller picture. This is where the inverse ratio comes in; the smaller the picture the greater is its brightness.

This means the brightness per identical area of surface, as per square foot. Each projection receives practically the same total amount of light.

Size of Image and Definition

It is of interest to take the views of a lens manufacturer on the best size or rather on the limit of size of the projected view. The Gundlach-Manhattan Optical Co. take the ground that there is an unavoidable loss in definition incurred by magnification This concern holds that the limit of size is about twelve by sixteen feet for the picture on the screen.

Such a picture is about 212 times the diameter of the picture on the film, so that its area is just short of 45,000 times that of the film image. The minute picture on the film receives about forty-five thousand times as bright illumination as does the picture seen by the audience.

The definition suffers in extreme magnification, because the photographic image on the film is not absolutely sharp to begin with. Its lack of sharpness is enormously increased by its magnification on the screen. No matter how good the lens is, the quality of the photograph governs the result. If the photograph is poor, good illumination and magnification will go to make its defects more perceptible, than if projected smaller. In the latter case it should better stand the high illumination. After all, bad illumination is a very poor way of hiding defects; moderate magnification is a very good way of bringing out the best that is in a picture, and is not an expedient to hide its faults.

Reflection from Lens Faces

Transparent substances, such as glass not only permit light to pass through them, but also reflect it at both exterior and interior surfaces. If rays of light fall upon a surface of a plate of glass in a direction perpendicular to its surface, only a small portion is reflected; nearly all enters the glass and passes through it.

If the ray or beam of light falls upon the surface of the glass at an angle from the perpendicular, in other words, obliquely, a part will enter the glass and will be refracted in so doing while a considerable part will be reflected from the surface. Thus if light falls obliquely on a glass surface only a part will enter the glass, and be transmitted. The percentage, which will be reflected, in the case of lenses, condensers or projectors, is so much light lost. The percentage of reflected light varies with the angle at which it falls on the glass surface. The variation bears no direct relation to the angle.

When the light falls at an angle of zero, which is perpendicularily, upon the outer surface of the glass, from 3.4% to 3.6% are reflected. As the angle of incidence, which is the name of the angle at which the rays fall on the glass surface increases, there is a slow increase in the percentage of light reflected. The increase is so slight, that at 30° the reflected light is but a little over 4%; at 60° it varies from 8% to a little over 9%.

If the crater of an electric lamp is placed at two and a quarter inches from the center of a 4½" condenser, the light will fall upon the margin of the flat surface of the condenser at an angle of incidence of 45°; at this angle the reflected light is only a little over 4%. This is the largest angle of incidence at that distance which can obtain on a lens of that diameter with the light so placed.

It is clear therefore that the fear so often felt, that a great quantity of the light falling near the margin of a condenser is lost, is a mistake. There is little more light lost around the margin by reflection, than there is from the center.

External Reflection

Light falling upon the outer surface of glass is never totally reflected. Even at an angle of incidence of 85° only a little over one-half the light is reflected.

TOTAL INTERNAL REFLECTION

When light is passing from the interior of a transparent substance, such as glass, at a great enough angle of incidence upon the inner surface of the glass, all of the light will be reflected. The internal angle of incidence, as it may be termed, at which this total reflection begins to take place, is not far from 40° for glass. If light passing through glass falls upon its inner surface at an angle from the perpendicular greater than 40°, none will be transmitted.

The action of total internal reflection in water can be very simply seen with a glass of water and a spoon or similar object. Pour some water into the glass, and set the spoon in it. Then holding the glass above the head, look up against the inside of the upper surface of the water, and the spoon will be seen perfectly reflected in the inner surface of the water as if it were a mirror.

It follows that the greater source of loss of light by reflection is when the light is emerging from a lens, not when it is entering it. It is quite conceivable that a short focus lens no greater in diameter than a condenser might reflect all of the light, that struck its inner surface near the margin.

ANGLES OF INCIDENCE AND REFLECTION

The angle at which light falls upon a surface is called the angle of incidence. More or less of it is reflected; if the surface is a rough unpolished one, the reflected light will be reflected in many directions; it is a case of irregular reflection.

The angles at which light falls upon a surface is measured or reckoned from the perpendicular to the surface. The same is true of the angle at which light is reflected from glass or any perfectly smooth surface, when there is no irregular reflection. This angle is called the angle of reflection.

When a smooth surface reflects light the angle of incidence is equal to the angle of reflection. Suppose a ray of light strikes a mirror at an angle; the reflected ray will leave the point on which the ray impinges at the same angle with the perpendicular, which the first ray made with the perpendicular, but on the other side of the same, so that the two rays may be pictured as a capital letter V.

The ray of light falling on a smooth reflecting surface and the ray reflected from such surface lie in the same plane.

Perpendicular and Oblique Reflection

The image of the sun as reflected from a surface of water, as from a pond, can be looked at without trouble when the sun is high in the heavens. When it is near the horizon its reflected image is so bright, that it dazzles the eye. The reason for this difference is that the light from the sun in the high heavens falls at an angle so near the perpendicular that little of its light is reflected. When it is near the horizon more of its light is reflected and the image is brighter, although the total light of the sun is less when it is near the horizon.

Standards of Light

The light given by a lamp is measured by various standards. The one most in use in all calculations and standardizations in this country is the international candle. This is a poor enough standard, as nothing is more uncertain than the illuminating quality of a candle. Many things affect it. The exact composition of the body of the candle has to be secured. This is more or less a matter of uncertainty. The temperature of the room in which it is burned affects its readings. It is supposed to burn at an exact rate of two grains a minute. Any departure from this rate affects the amount of light which it gives.

If it burns too much or too little a correction is applied by the rule of three, as it is called, to reduce the readings to the true ones. But while this is correct on its face as a matter of fact the correction is not a perfect one, and if a candle burns more or less than the standard weight of material in the minute, the readings corrected for the excess or deficiency will not be correct.

In hot weather difficulty is experienced in taking observations of candle power of lamps, with standard candles, on account of the way the heat affects them. Sometimes they are put upon ice to get them chilled before using them on the photometer.

Standard Incandescent Lamp

The introduction of the incandescent Lamp as a working standard has overcome these troubles. Special lamps are rated for their candle power and these are used in testing the illuminating power of lamps.

PHOTOMETRY

The photometering of a lamp is the determination of the light it gives as compared to the standard candle. This is an operation in physical measurement, which is hardly within the scope of the work of the motion picture engineer. Yet it is well that he should know the general lines on which the work is done.

There is much confusion prevalent as to the conditions obtaining in the projection of pictures on the screen. There are evident in books sometimes the most uncertain ideas as to the relations of throw to light received by the screen.

LIGHT RECEIVED BY SCREEN

Referring to the diagram, page 106, take the original source of light to the beam from the center of objective. The image on the screen is so large and the objective so small that the latter can be taken as a point, or as a source of light without any considerable area.

The rule of inverse squares given before comes in here. The screen at a distance of fifty feet will be lighted with one fourth the intensity or brightness that it would be lighted with at a distance of twenty-five feet. At one hundred feet it would receive but one quarter the light it would receive at fifty feet and only one sixteenth the light it would receive at the twenty-five foot distance.

Fifty is two times twenty-five, and the square of two is four; the inverse ratio of one and four is one to one-fourth.

Putting the above as an arithmetical proportion we have:

$$1/25^2 : 1/50^2 :: 1/625 : 1/2{,}500 \text{ or as } 4 : 1.$$

Find what the relative distances are; take their squares as the denominators of fractions having one for numerators, and the fractions will express the relative light received. The simple ratio will be obtained by dividing the larger denominator by the smaller one.

Let the distance be forty feet and sixty feet. The fractions obtained as above are 1/1,600 and 1/3,600. The ratio obtained by the division of both denominators by 1,600, 'for that is what it comes to is 1 to 2 1/4. At the shorter throw the light would be two and a quarter times stronger than at the longer one.

BRIGHTNESS OF IMAGE AND LENGTH OF THROW

Having gone this far the structure is to be destroyed in a sense, as regards the effect of length of throw on the brightness of a picture on the screen. The distance of the screen from the projection machine has nothing whatever to do with the brightness of the projection directly speaking. It has only to do with it as far as it is responsible for its greater or less size. In general terms a picture will vary in brightness of projection in proportion to its area, whether the focus of the lens is such as to give it a long or a short throw. The idea that the length of throw directly affects the brightness of the projected picture is erroneous.

LUMINOUS FLUX AND THE LUMEN

We have seen that the light of a candle is the standard of the light-giving power of a lamp. The scientific or technical name of the rate of flow of light from a visual point of view, with reference to its effect on the human eye, in *luminous flux*. The light from a point of light goes out in all directions. Suppose now that a unit solid angle is taken. A unit solid angle is such an angle as would be included in a pyramid. Referring to the same diagram of the inverse squares, we see there a solid angle represented in perspective in the drawing. The light contained in such an angle as produced by one international candle is called a *lumen*.

This makes the law of the inverse squares still clearer. For whether the surface lighted is near to or far from the source of light the same total is received, and as the area is larger and larger as it is more and more remote from the source of light, its lighting is naturally dimmer as the area increases in size. Whether near or far it receives the same luminous flux, the same number of lumens, as long as the same number of candles are expended and within the definite solid angle.

ILLUMINATION

The fact that more or less light is received by a surface is expressed by reference to the density of the luminous flux upon it. The density of luminous flux is called the *illumination*. If the illumination of a surface is even its illumination is the flux per unit of its area.

THE LUX

The practical unit of illumination is equal to one lumen per square meter. Imagine a sphere of 2 meters diameter with a point of light of one international candle power at its center. Every square meter of the inner surface of the sphere would receive one lumen of luminous flux. The amount of illumination given by one lumen per square meter is called a *lux*.

These units seem rather abstract at first sight, although they are not really so. For our purposes they would be better if expressed in American measures. These can be given readily.

THE FOOT-CANDLE

The illumination given by an international candle at a distance of one foot is called a *foot-candle*. It is equal to one lumen per square foot.

LUMINOUS INTENSITY

The power of a lamp or candle is its *luminous intensity;* it is also called its *candle power*. The latter expression tells how strong the light is in candles. The light of a candle is something very understandable.

So if you wish to expresss the illumination your screen gets from the light coming through the objective, you can express it in luxes. If it is lighted with ten luxes of illumination, it receives ten lumens on each square meter of its surface. A lux is the light given by a candle at a distance of one meter and spread over an area of one square meter. It is a meter-candle. The ten luxes are equal to ten meter-candles.

In American measure the illumination of a screen would be expressed in lumens per square foot, which would be in foot-candles. An illumination of one foot candle would be about ten luxes.

Thus the lumen is the light contained in a solid angle of a little short of sixty degrees, which angle is called a stereradian. The representation of such a solid angle is a sort of picture of a pyramid. A lamp of one candle power at the apex or point of the solid angle will fill it with one lumen of light. If the area covered by this amount of light is large or small it makes no difference; the light is always one lumen. On the larger area there is less brightness as there should be, because the lumen, which is a fixed quantity of light is spread over a greater space. One lumen spread over one square foot is the foot-candle, and this is what most interests us in this country.

SCREEN SURFACES

The qualities of screens are now no longer matters of surmise; the efficiency of materials for projection purposes is a subject for definite testing and accurate determination. The usual unit for expressing the work of screens of different materials is the foot candle. This is the light which is given by a standard candle at the distance of one foot. If a candle of this description is held one foot from a surface, the surface will be illuminated by one foot candle at the point directly in line with the candle. This is simple enough.

LIGHT RECEIVED BY THE SCREEN

But the quality of the screen has nothing to do with the amount of light, which it receives. The problem is to determine how many foot-candles of light the screen reflects to the audience. The screen has for this purpose to be regarded as in a sense the source of light, as it really is for the audience. For them there is no projection machine with its powerful arc or incandescent light; all they know of the light produced is the light which comes from the screen, and this is only reflected. The light reflected from the screen is to be measured in foot-candles. The amount of this light depends upon the light projected upon it. It follows that the determination of the quality of the screen must be based upon its power of giving a proper number of foot-candles to enable the pictures to be properly presented, yet to avoid glare. In each case, where a screen in final position is to be tested, it will not be so much the quality of the screen material as the faculty of the light of the lamp and the screen together giving an illumination of the proper number of foot-candles to suit the hall, its relative width, its size, the length of throw and other less controlling factors.

THE FOOT-CANDLE METER

A very simple and portable apparatus has been devised for measuring the illumination of a screen. It is the Foot-Candle Meter.

A box has mounted within it a small lamp of standard power, which has been accurately rated. Its light for a definite voltage is known, and in making the tests the voltage is fixed by the use of a voltmeter. Its light shines through a number of small round holes filled with translucent glass. The lamp is in the center of the box, and the holes are distributed along its whole side. The central hole nearest the lamp receives the most light, the holes further from it receive the lesser amount of light. Each hole represents a stated number of foot candles.

The machine is taken to the stage and is held as near the screen as possible. The holes range in illumination through quite a considerable extent. The illumination of the holes is compared with that of the surface of the box and a hole is picked out, the glass filling which is as bright as the screen around it. The reading of the foot candles of illumination of the hole corresponding in brightness gives the foot candles reflected by the screen.

It is considered that the foot candle meter gives a reading to an accuracy of 85 to 90 per cent. This is quite close enough for all practical purposes.

Details of Foot-Candle Meter

The apparatus is contained in a stamped metal case, 7⅞ x 6 x 1½ inches. When the interior of the case is opened to view the following contents appears. Along the upper part of the case are three flashlight batteries. These are arranged in a row so as to constitute a single cylinder, the length of the case. Below these and like them arranged horizontally as the case is carried is the photometer or foot-candle meter proper. Below these come the rheostat and the voltmeter. The photometer is to be described, for the rest is simple, being merely the ordinary electrical appliances.

The photometer, as we may call it, is a long case, one side of which is closed with a plate of clear glass. At one end of the case the electric lamp is fixed, inside it and screened by a piece of ground glass. The strip of clear glass, which forms one side of the small case, is covered with semi-opaque white paper, with a row of ⅛th inch holes extending its full length. Over this paper is a piece of translucent paper. The holes form a series of spots on the surface, when the lamp is lighted, and the nearer the lamp they are the brighter do they appear. Their brightness for the light of the lamp at standard consumption is determined once for all. The holes may run from 0.5 up to 25-foot candles illumination, and this illumination or brightness is found to vary at a rate inversely between the second and the third power of the distance from the lamp.

Exposed to a source of intermediate value, more than half and less than twenty-five candles, the white surface of the box will seem brighter than some of the holes and darker than others. The hole of the same brightness as the surface gives the foot candle of illumination the surface of the box or case is receiving. The instrument it will be seen is simplicity itself.

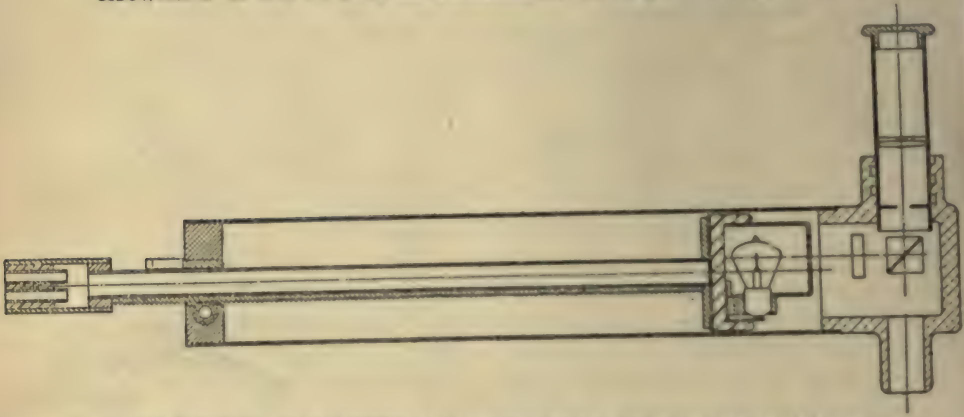
Theory of Foot-Candle Meter

The idea of the instrument, the Foot-Candle Meter, is that the disc covering the holes are illuminated by a light of regulated voltage, which has been rated so that its candle power is known. Then the distance of each hole from the lamp within the box is known, so that the illumination of each glass disc is definitely known to be a certain number of foot-candles. The surface of the box is lighted by some external source of light, and its illumination is rated in foot-candles, and the number of foot-candles at which it is rated, is that of the disc, whose brightness blends into that of the disc of some known foot-candles of illuminations. Thus in the illustration the series of discs are seen graduating in brightness; at one end they are darker than the surface of the box; at the other end they are brighter; in the center they blend into the cover. Therefore at this central point as the meter is supposed to read, the discs give the illumination of the surface of the apparatus.

If the disc, whose surface blends into that of the surface of the meter, is marked as five foot-candles, the light received by the apparatus is of five foot-candles. The instrument can be carried about from point to point in the hall and the foot-candles received at each of such points is given by its readings.

This illumination is that given by the screen and received by the eyes of the spectators at the points tried. Nothing could be more practical and simpler. It can be used by any person of reasonable capability, and the results are so direct, that they appeal to the most practical minds.

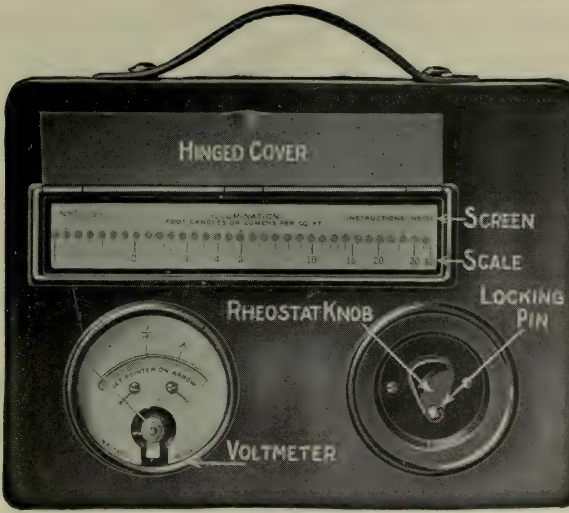
In the case of light received from so large a surface as the area of the screen, the rule of the inverse squares is no longer true. The law in question, which states that the intensity of light varies with the inverse square of the distance has been fully explained elsewhere. It will be seen on reference to the explanation, that the truth of the law depends on the condition that the light shall be given by a point, or by a source so small as to be virtually one, and that the law is a matter of geometry and not of any hidden and mysterious quality of light. This is said because in some places in the literature of the subject it is made to appear that there may be some mysterious way, in which light diminishes of itself as the distance from the lamp or other source of light increases. It is a matter of the light spreading over a larger area as it is farther from the source of its origin. Therefore the law does not hold for the case of the great area of illumination of the bright screen.



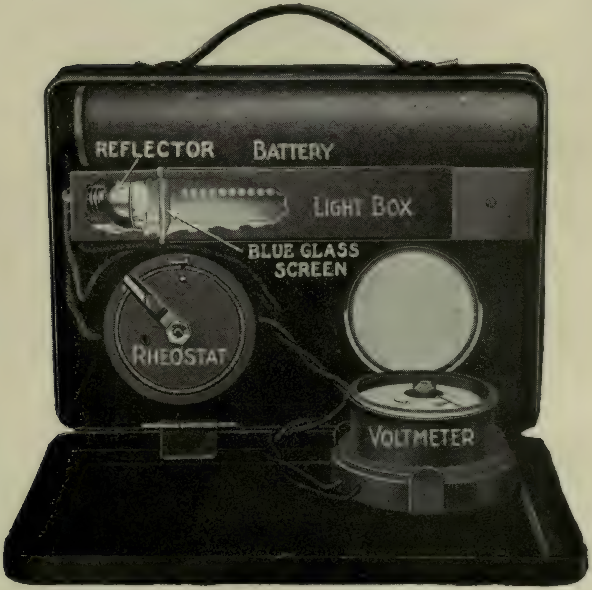
CROSS SECTION OF MACBETH ILLUMINOMETER. THE STANDARD LAMP IS MOVED IN AND OUT UNTIL AN EVEN ILLUMINATION IS OBTAINED. THERE IS A SCALE ON THE BAR WHICH GIVES THE CANDLE-POWER OF THE LAMP BEING TESTED

THE MACBETH ILLUMINOMETER

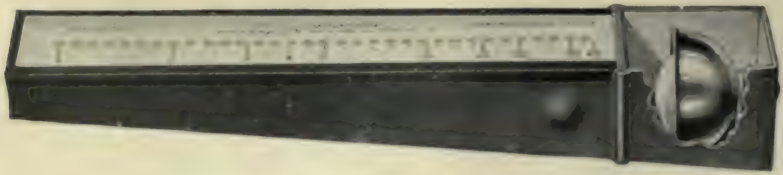
There are more elaborate and more accurate photometers for this class of work. The Macbeth Illuminometer is one of the best


HINGED COVER
ILLUMINATION
FOOT CANDLES OR LUMENS PER SQ. FT.
INSTRUCTIONS INSIDE
SCREEN
2
3
4
5
10
15
20
30
SCALE
LOCKING PIN
RHEOSTAT KNOB
SET POINTER ON ARROW
VOLTMETER

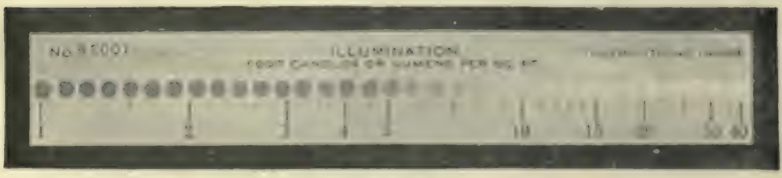
EXTERIOR DETAILS OF FOOT-CANDLE METER


REFLECTOR
BATTERY
LIGHT BOX
BLUE GLASS SCREEN
RHEOSTAT
VOLTMETER

INTERIOR DETAILS OF FOOT-CANDLE METER



DETAILS OF LIGHT BOX


ILLUMINATION
FOOT CANDLES OR LUMENS PER SQ. FT.
1
2
3
4
5
10
15
20
30
40

SCREEN OF THE FOOT-CANDLE METER INDICATING 10 FOOT CANDLES

USING FOOT-CANDLE METER

MACBETH ILLUMINOMETER

known, and is comparatively portable. It is not so portable as the simple foot candle meter we have just spoken of, but is a very accurate instrument, as its readings can be depended on to within a few per cent of the true illumination of a surface. There are other instruments still more bulky and it is on instruments of this type that dependence is to be placed for really accurate and authoritative figures. But for practical and quick individual determinations of the screen illumination in single cases the simpler and more portable instrument cannot be too highly recommended.

ANGULAR POSITION OF OBSERVER AND LIGHT FROM SCREEN

It will be found that the readings of the foot candle meter will diminish but little as the distance from the screen increases. They will change a great deal as the angle, at which the light from the screen is received varies. This means that at the sides of the hall the readings will be lower than in the center, because the screen will give less light sideways than it will directly at right angles to its surface. The ratio between the light emitted by an illuminated surface at various angles with such surface, is a test of the quality of a screen material for a given hall. It is found that a material, which gives the highest illumination for a given light falling on it, shows the greatest difference between the light reflected in a straight directon and in an oblique one. On the other hand the material, which, made up into a screen, gives the most even light in all directions is the one which is the most wasteful, as giving the least light in a perpendicular line to its surface.

SCREEN-SURFACES

A most interesting and valuable study of this quality or reflection of light from different screen materials, with reference to the two definite qualities of total reflection and equality of reflection in varying angles, which means to one side of the center of screen or of the hall is contained in a paper read before The Society of Motion Picture Engineers by Lloyd A. Jones and Milton F. Filius, at the meeting of October, 1920. They used the Macbeth photometer, a more accurate and complicated instrument than the Foot-Candle Meter we have described. The accuracy is considered to be as high as 95 to 98 per cent. No less than thirty-six screen materials were tried. Their reflecting power at various angles were determined and the results tabulated, and curves expressing their qualities were plotted. The results were definite in one respect. The strongly reflecting screen, the one of presumably the most economical quality, because of highest reflecting power, was that of greatest uneveness of reflection. Either economy or even illumination has to be sacrificed.

EFFECT OF MATERIAL ON ILLUMINATION AT DIFFERENT ANGLES

The measuring the light reflected from a screen is the measurement of the brightness of the picture it projects into the hall. Here another factor of projection comes into the field, that of glare. Too bright a picture is found to be disagreeable to the spectators. A very highly reflecting screen, with a strong light in the lamphouse does not represent the proper and agreeable projection of pictures. The audience are there for enjoyment. If they leave with tired eyes the exhibition will be criticised unfavorably. This above all things is to be avoided, for the motion pictures are produced to please, not to weary the eyes and give headaches.

A screen of high reflecting power for a direction at right angles at its center, and of poor reflecting quality at oblique angles, will exact a very high illumination if the spectators in the sides of hall are to get light enough to see well. If they get this degree of light from the screen, which is at an oblique angle to them, the spectators in front of the center of the screen will be wearied with excess of light. This is glare. It is a thing to be avoided. The selection of the screen material will have everything to do with its avoidance, and one of the most advanced of the developments of the art is in the line of surface and material of screens.

SCREENS FOR NARROW AND FOR WIDE HALLS

In the paper by Messrs. Jones and Fillius referred to above, the point is strongly brought out that a screen which suits a long narrow hall, will be altogether unsuitable for a wide and shallow one relatively speaking. A second conclusion is that if a wide and relatively shallow room is to be used for projection a screen of less economical characteristics will be required, than would be for a room of narrow width compared to its length.

THE NARROW PROJECTION HALL

In a practical way it has long been recognized that the narrow hall was the best for the projection of pictures. As the exhibiting halls increased in number, quite small rooms were converted into motion picture halls. It happens to be the case that the class of rooms or halls thus utilized in the smaller towns and cities of the country at large, tended to the deep and narrow shape. In other words, the most usual shape of such halls was that best adapted to the work. In the early days a screen was a screen; a sheet stretched, or sometimes unstretched and full of wrinkles and folds, was esteemed good enough for projection purposes. All that saved the day was the favorable shapes of the halls.

THE WIDE PROJECTION HALL

Now all is changed. The former theatres are being utilized as motion picture halls, and the subject of screens has received a great deal of attention, but at the same time no more than it deserves.

CHAPTER VII

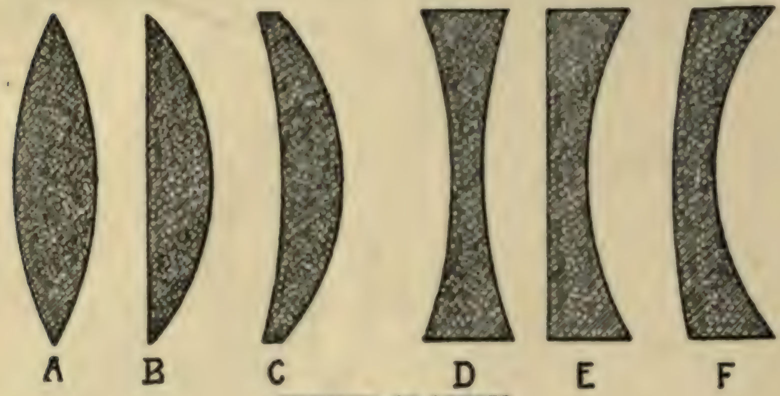
CLASSIFICATION OF LENSES

THE double convex lens is the one used in ordinary uses to magnify objects. It is convex or bulges outwards on both sides. The convexity may be the same for both faces or may vary for the two faces.

The plano-convex has one face a plane or flat, the other is convex. This is a form much used in condensers.

We have next a concavo-convex lens. This is sometimes called a meniscus. Its section is that of the crescent moon.

The three types of lenses so far described are all magnifying lenses; the last title of each double name ending in convex may be supposed to tell this, as a convex lens is a magnifying one. Next we come to three lens-shapes, which diminish instead of magnifying, and their titles end in the word concave. This may be understood as telling that they are of the concave or diminishing kind.



SECTIONS OF LENSES

The first is the double concave. The curvature of the two faces may be the same or may be different for each.

Next there is the plano-concave, flat on one face and concave on the other.

Then comes the convexo-concave, also a diminishing glass as a rule, although it may be almost without any effect, if the two faces have the same curvature. The fact that its name ends in concavo distinguishes it as a diminishing lens. This is the front lens of the rear combination in some objectives.

A simple disc of glass might be included in the list, but it never is; a lens must have the power of refracting light.

The Lens in Projection

It is fair to say that the essence of projection is in the lens. The light is produced from as small a source as possible; the nearer the luminous area, the crater, resembles a point the better is the light. The rays of light start on their course as a cone of rays; they are caught by the condensers, a pair of comparatively large lenses, and their courses are changed, so that instead of spreading out as they go they converge. They pass through the picture on the film or on the slide as the case may be, and enter the objective, another lens or set of lenses. This brings the image on the film or glass to a focus on the distant screen.

Size of Picture to be Projected

It is also fair to say that few people realize how small is the picture on the film, which is seen life size or more on the screen. When we stop to realize that the really minute photograph is so perfect that it can be successfully magnified to the requirements of a fifteen-foot screen, and to those of a much larger one, if desired, we hardly know which to admire most, the photographic side of the achievement or the optical one.

Refraction of Light in Lens

The action of a lens depends upon what is termed the refraction of light. When light passes from one medium into another of different density, it will be bent from its course, if it strikes the new surface obliquely, and it will be bent more by some substances than by others. The relative refracting or bending effect of any substance is expressed as its index of refraction.

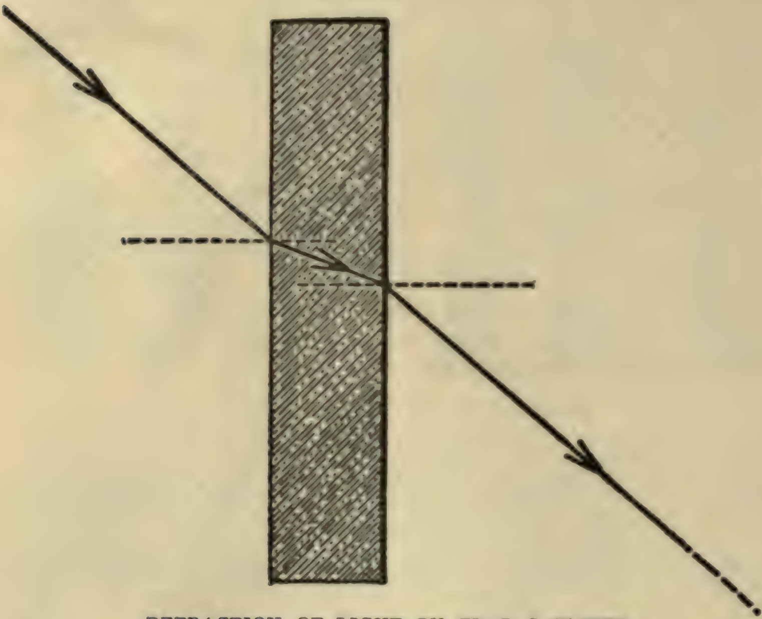
The easiest way to picture the action of a substance upon a beam of light entering it obliquely, is to think of the beam as having a front at right angles to its line of progression, like the front rank of a column of soldiers marching.

Suppose it is passing from a rare into a denser medium. It will be retarded in its progress, and as the retardation will affect one corner of the front of the beam first, because that will first strike the surface of the denser substance, and as the whole front will be thus progressively retarded, the front will swing around through an angle and the beam will go on through the denser substance in a new direction.

The diagram shows what takes place when a beam of light passes from the air into a piece of glass obliquely.

Analogy of Soldiers and Ploughed Field

To picture what happens an analogy is very often used, that of the soldiers and the plowed field. If an advancing body of soldiers represent the beam of light, and a plowed field the glass, it is clear that they will be retarded in their rate of marching when they enter the field. But the end man at the front



REFRACTION OF LIGHT BY FLAT S WAVES

who first enters it is the first to be retarded, next his companion enters and is retarded too, but a moment later. The effect will be to swing the front through an angle, and start the regiment off in a new direction.

This action the diagram also represents. On leaving the denser medium, the glass, the light is again refracted, but in the opposite way. The front swings around through an angle as the light emerges from the glass and a new direction of progress is taken.

If the glass has parallel sides the light will be refracted on emerging just the amount required to restore it to its original direction. This is shown in the diagram.

The reader can follow out the analogy of the soldiers, and he will see that this is what they will do on leaving the plowed field.

Coming back to our soldiers some of them may be supposed to have shorter legs than others and to be most affected and retarded by the difficulties of the plowed field. These then will be most deflected from their line of march.

Ether Waves and Color of Light

Light is supposed to be caused by waves of the ether. The waves vary in length; those of the violet colored light are the shortest, those of the red colored light are the longest. These are in general terms the extremes; the wave lengths of other colors come in between. We do not know how many different wave lengths there are; each pure color has its own wave length, and no one knows how many pure colors there are.

In the illustration a diagram of the passage of light through a prism is given. It will be seen that the light is refracted as described, and that the light of short wave length is most refracted. The refracted light is therefore drawn out into a band of many colors, and this band is called the spectrum.

The spectrum is a wonderful instrumentality for the study of many things in chemistry, astronomy and other branches of natural science. But as far as projection is concerned the spectral colors are one of the difficulties to be coped with, and a brief description of the trouble in question, chromatic aberration, will be given here.

Chromatic Aberration of Light

If light is passed through a lens it will be refracted, and just as in the case of the prism some light will be more refracted than other light, according to the wave length. The result is that, if such a lens is used to look through, or is used for projection, colors will tend to appear, especially along the edges of the image or object seen.

Suppression of Chromatic Aberration

To show how these color effects can be suppressed, so that a pure uncolored image can be produced, we may go back to the prism.

The spectrum formed by corresponding prisms of different kinds of glass vary in length; this is the same as saying that some glass refracts light more than other glass. Flint glass is far more powerful as a refracting substance than crown glass.

We may take the case of a compound prism. The crown glass portion by itself would give a spectrum of the colors of the rainbow. The prism of flint glass is so shaped as regards its angle, that by itself it would produce a spectrum of the same length as that of the crown glass prism. But as it is reversed in position, the two spectra are combined, and the rays, which would be separated by either prism alone, are so superimposed by the two prisms that the colors of the spectrum do not appear and a colorless band is produced. The reason that a band is produced is because the left and right sides of the combination are not parallel; the refraction is less, the band is shorter than would be the case for either prism alone, but this sacrifice of power is made to secure a colorless band.

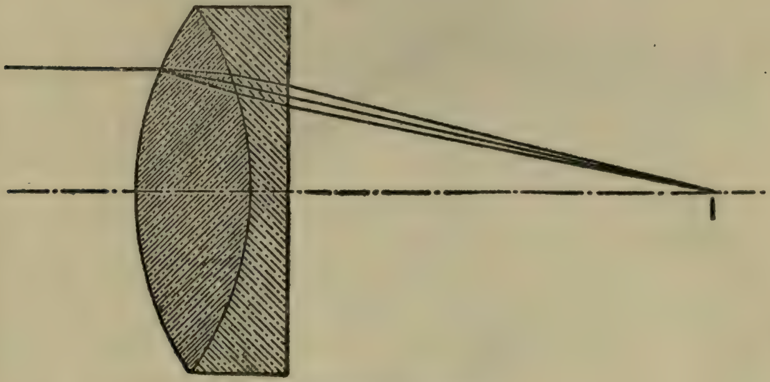
This is the exact method used to make lenses, which will give images free from colored edges.

Achromatic Lenses

Suppose a convex lens is to be made. A convex lens of crown glass is first made, of more than the desired curvature, in other words of shorter focus than is needed. A concave flint glass lens is made to fit against it as shown in the cut. It is practically the case of the reversed prisms of the two glasses. The flint glass prism corrects the color-producing property of the crown glass one, and the combination gives a colorless image.

Such a lens is called an achromatic lens. This is a word derived from the Greek, and means colorless.

The magnifying power of the crown glass lens is reduced by the concave flint glass lens; the focal length of the compound lens is much greater than that of the single crown glass one. Accordingly this feature has to be provided for in the grinding of the glass. The crown glass lens must be given a greater curvature to compensate for the action of the convex lens of flint glass.



ACHROMATIC LENS

Achromatic lenses are in universal use for all important functions. Projection lenses especially must be absolutely achromatic. The production of colored pictures on the screen is highly desirable, but uncorrected lenses will not give them; such lenses will only show colors along the edges of the picture, where they are not wanted and where they have no relation to the colors of natural objects.

SPHERICAL ABERRATION

A lens ground in spherical curvature will not bring rays of light passing through it to an accurate focus. Those passing through the central portions will be brought to a focus at a point more distant than that attained by those passing through the portions of the lens nearer its edges.

The diagram shows this condition; the distance, G, F, between the nearest and the most distant foci is called the longitudinal spherical aberration of the lens.

The lens maker, by carefully studied out combinations, makes this aberration as small as possible. In general terms it is less for a lens of small angular opening than for the other type. For a 15° opening lens the longitudinal aberration will be about one-fortieth the focal distance. For a 45° lens it will be over one-third the focal distance.

Formulas based on the radius of curvature of the front and rear surfaces of lenses have been worked out; in one case the favorable proportion of front radius of curvature to rear has been calculated as 6; 1; the most curved surface of the lens is to be placed on the outer or screen side of the lens tube.

THE FOCUS OF A LENS

Focus is a Latin word meaning fire. If the rays of the sun are passed through a convex lens, at a certain distance from the lens a little bright and hot spot will be produced. If this is caused to fall upon a piece of paper, if the glass is powerful enough the paper will be set on fire. If it is received on the hand, the little spot will burn you. This bright fire-like spot is produced at the focus of the lens. The name focus or fire is quite appropriate.

FOCAL DISTANCE OF A LENS

The distance from the center of the glass of the lens to this spot is the focal distance or focal length of the lens; it is generally called the focus of the lens for shortness.

If the lens is not corrected for color or chromatic aberration, it is evident that there must be a number of foci for a lens of that character, one for each color or wave length of the various rays of light passing through it. It is only an achromatic combination that will have a single definite focus.

As projection lenses are achromatic there is a definite focus for each one.

While strictly speaking the rays of the sun converge or approach as they travel to the earth, for us they are exactly parallel, on account of the great distance of the sun from us. The focal distance of a lens is the distance from the optical center to the center of the image which it forms, when the rays of light bearing the image to the lens are parallel.

FOCAL IMAGE OF THE SUN

The little bright, hot spot produced by the lens when the sun's rays are caused to pass through it is not a point, or the crossing of rays; it is an image of the sun as truly as the picture on the screen is an image of the photograph on the film. There is much misunderstanding of the action of the lens under these conditions and of the action of the burning glass.

THE BURNING GLASS

The approximate diameter of the image of the sun produced by a convex lens, is one one-hundredth of the focal length of the lens. All the heat received by the area of the lens and transmitted through it is concentrated on this small area. The heat may be quite intense; it is with any lens of fair size and convexity enough to set paper on fire. A lens used for this purpose is called a burning glass.

It is fair to say that the burning glass is at the root of the word, focus, which means fire. It is next in order to understand precisely what the focus of a lens is and all that it implies.

ACTUAL AND VIRTUAL FOCUS

There are two kinds of focuses or foci; the actual and virtual. These are quite distinctive. Every convex lens has its principal focus, and it is by this that it is rated or described. Then every other focus greater in distance from the lens centre than is the principal focus, has its conjugate focus; for every object at any point other than the principal focus, there is a conjugate image; object and image are conjugate to each other. All this will develop as we go on.

In considering the theory of focal relations, it will be assumed that the lens is perfectly corrected for all aberrations.

Assume that the light from a distant object is received on the face of a lens, convex in shape. This includes the plano-convex and the meniscus shape, as long as the lens is what is commonly called a magnifying lens.

The object must be so distant that the light comes in parallel rays. Practically speaking this is easily obtained; for an ordinary lens objects at a distance of one or two hundred feet give substantially parallel rays.

The Focal Image, How Produced

An object is visible by the rays of light coming from it. From every point of the object rays proceed in all directions, so that each point of the lens receives rays from each point of the object. Now take one point of the object alone.

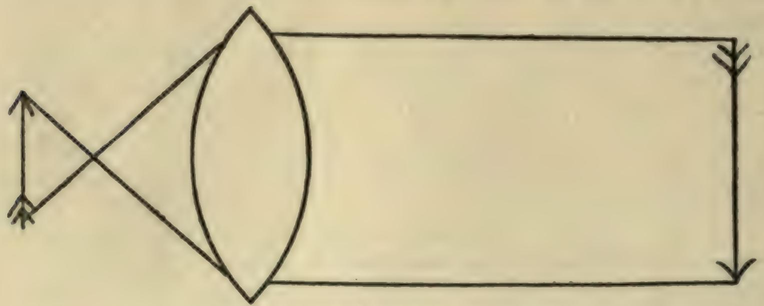
A multiplicity of rays from this point fall on the surface of the lens. Wherever a ray falls on the surface in question, it is refracted and bent out of its straight course, and the refracting is such that it brings all the rays from the given point of the object to a single point on the far side of the lens, so that the point is thus reproduced in space by the action of the lens.

From every other point of the object rays are emitted, and they fall on all parts of the surface of the lens. Each point is reproduced by refraction as already described in space. Each point is thus reproduced at the same distance from the lens. Thus an accumulation of reproductions of points of the object are produced in space, at a uniform distance from the lens, each in its proper relative position, so that the result is a reproduction in space of the whole of the object.

Focal Image of a Distant Object.

Every part of the surface of the lens is working on each individual point of the object; the entire area of the face of the lens is concerned in the reproduction of each point of the object. The action is made clear by a diagram.

The arrow represents the object, assumed to be so far from the lens that it affects it with practically parallel rays. All rays from



LENS DIAGRAM PARALLEL RAYS

the point of the arrow are concentrated by refraction on the far side of the lens. Wherever they strike the lens it refracts them to the one point.

Take the other end of the arrow, it will be refracted as shown, no matter where the rays from it strike the lens, and they will strike every part of it. But all will be refracted.

The same will apply to the center and to every other part of the object, which may be of any shape whatever. An arrow is only used as a convenient and usual object for this kind of discussion.

All parts of the arrow will be refracted to points on the same plane, which is the same as saying, at the same distance from the plane of the face or center of the lens.

The Focal Plane

This plane in space is the focal plane of the lens; the distance from the center of the lens to the plane is its focal length or focal distance, often called its focus. As the distance is fixed by the use of parallel rays, it is the principal focus.

Refraction of Rays from Objects

If an object is placed inside the principal focus, closer to the center of the lens than is the principal focus, the rays of light from the object, after passing through the lens, will form no image.

Refraction of Rays from an Object at the Principal Focus

If an object is placed at the principal focus of a convex lens the rays from it will be refracted into space in parallel lines and theoretically an image may be assumed to be formed only at an infinite distance.

If an object is placed beyond the principal focus and within twice the focal distance of the centre of the lens, an image will be produced larger than the object.

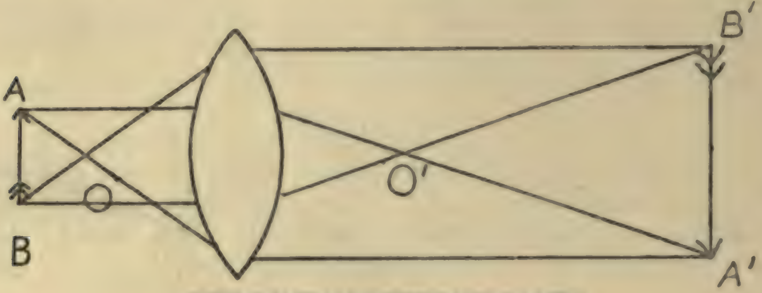
If an object is placed at a distance from the centre of the lens greater than twice the principal focal distance, an image smaller in size than the object will be produced.

It will be seen that the last two conditions are the reciprocals of each other.

Refraction by a Lens Illustrated

The general laws of refraction through a convex lens are shown in the diagram.

The section of a convex lens is in the centre of the figure. On each side of it the principal foci, one for each side are shown, O and O′. The arrow, A. B., is the object to be projected or to have its image produced. Let a ray of light be taken as passing from one end of the arrow A, through the focus of the lens on its own side, and meeting the surface of the lens as shown. As this is a ray passing through the principal focus it will be refracted on passing through the lens in a straight line parallel to the axis of the lens, which in the case as drawn, is the horizontal line through the centre of the lens.



LENS DIAGRAM CONJUGATE IMAGES

Let another ray of light be followed as it starts from the center of the arrow, and passes through the centre of the lens. This will take a course parallel to the extension of the original line of travel. In other words the ray passing through the centre of the lens will follow a straight course.

Next follow the course of a ray starting from the same point, A, and going in a line parallel to the axis of the lens, and impinging on it as shown. This ray must in accordance with what we have seen so refracted as to pass through the principal focus of the lens on the further side. This is the focus, O′, in the diagrams.

We have now traced the course of two rays; they both meet or intersect at the point, A′. The image of the end, A, of the arrow is produced at the point, A′.

CONJUGATE IMAGES

In a perfect lens all the rays from A, or from any point of the object will be refracted to the one point on the further side of the lens. In the diagram the process just described is repeated for the other end of the arrow. The two images are conjugate. The arrow, A′, B′, could be taken for the original object and its projection could be traced so as to produce the arrow, A. B, as its image. It is all reciprocal or reversible.

CONJUGATE IMAGES AT TWICE THE FOCAL DISTANCE

In the diagram the arrows are placed at twice the focal distance from the centre of the lens. In this arrangement of distances they will be of the same size.

But if the object is moved closer to the principal focus, its image will be produced at a greater distance from the lens than its own distance therefrom, and will be larger.

If the object is placed at the principal focus there will be no image because the rays as refracted will be parallel, and an image can only be produced by intersecting rays.

If therefore the image is to be larger than the object, as in the case in projecting films or views, the picture on the film or lantern slide must be placed at a distance from the lens centre less than twice the principal focal distance, and greater than the principal focal distance.

IMAGES WITH LONG AND SHORT FOCUS LENSES

There is a practical point to be mentioned here. It is easier to secure an exact focus with slightly converging rays rather than with those which converge at a large angle. A long focus lens with distant screen or with a long throw is easier to keep in focus than a wide angle lens with short throw.

If a lens consists of a single piece of glass and is of identical curvature on each side, focal distances are measured from the centre of its body or form, not from the surface. Such at least is the correct conception of the focal distance. It should be taken as measured from the center, not from the surface of the lens.

The above applies to a single lens of symmetrical contour. If the sides of the lens are of different curvature the focus should theoretically be measured from a plane a little to one side of the middle point of the axis.

THE EQUIVALENT FOCUS AS OFTEN UNDERSTOOD

An objective generally consists of several lenses mounted in a tube of brass. This tube may be of several inches length; it may have a number of lenses in the tube, some at the ends, and perhaps one in the middle of the tube between the two end ones. In such an objective there are two foci. One is the distance from the rear lens to the focal plane; this is called the back focus. It is used as the place whence the distance of the aperture from the lens is measured. It is, in the case of a long tube lens, considerably less than the real focus. The latter is taken as approximately the distance from the centre of the length of the lens tube to the focal plane. Thus if it was found that a lens produced a focal image at a distance of two inches from the lens nearest the light, which is called the rear lens, and if the rear lens was mounted with the other lenses of the combination in a tube six inches long, the focus of the lens as a whole would be taken as five inches. To the two inches distances measured from the face of the rear lens, as just described would be added one-half the length of the tube in which the combination was mounted.

THE BACK FOCUS

The distance from the face of the rear lens to the focal plane is called the back focus of the lens; the distance from the centre of the length of the lens tube to the same point is called the equivalent focus. This distance is the sum of the back focus and of one-half the length of the lens tube, as just described.

The equivalent focus is an approximation to the true focus of the combination. As it is not a convenient distance to measure directly the placing of the aperture, which means the placing of the film, and other focal measurements, are generally referred to the back focus. This is merely a matter of convenience; the back focus, literally speaking, may be said to mean nothing; it cannot be used for calculations of size of screen picture; for this the true focus of the lens should be used; even the equivalent focus is not always the true focus.

The leading manufacturers of objectives are prepared in the fullest sense to give service; they prefer to calculate the lens needed after they are told the size of projected image required, and throw. The size of the aperture should also be told, as it may not be standard.

The Virtual Focus

The virtual focus is a thing to be understood, although it hardly applies to projection, as far as the operator is concerned. If a real focal image is produced by a lens it can be seen, as if it were a real thing. If a piece of ground glass is so placed as to receive it, a reproduction of the original will be seen on the glass. The picture projected on the screen is the focal image of the transparency or photograph on the film or slide as the case may be.

The Virtual Image

The virtual image differs from the real focal image in one respect: it is always erect, while the true focal image is upside down. The virtual image enters into the operation of the opera glass, and of the compound microscope. In projection work it is the real focal image, which concerns us, although the optician may have to take the virtual image into consideration in calculating the curvatures of the lenses of a combination.

CHAPTER VIII

DESIGNATION OF LENSES

THE size of a lens is expressed by stating its diameter, as a four inch lens or a one and a half inch lens. But sometimes a lens is specified and named by its focal distance. Thus it is quite frequently the custom to call condenser lenses by their focal distance. Condenser lenses are generally of four and one-half inches diameter. Sometimes they are a little smaller, but not often larger. Many condenser combinations consist of two lenses of different focus. Frequently the rear lens, the one nearest the lamp, is of six and a half inch focus, and the front one is of seven inches and a half focus. It is a general usage to designate each of the condenser lenses by its focus and to speak of the six and a half inch lens or of the seven and a half inch lens.

This practice must be realized and watched for, not only in the case of condenser lenses but even in the case of others, although the designation by diameters is more usual.

THE LENS APERTURE

The aperture of a lens is the useful opening, through which it passes light. A lens may be of any given diameter, but in order to get good results it may be necessary to cut off part of its outer area to dispose of spherical or chromatic aberration. In photography this is very essential, and the working aperture of a lens depends on the diameter of the opening in the stop, which may have been employed. The maximum aperture of the lens would be that of the largest stop which it would tolerate. The more perfect the lens in general terms the larger will the aperture of such stop be. This in the case of projection lenses is as near the diameter of the glass disc of the lens as possible.

Often in projection lenses there is no stop. The aperture of the lens in such cases is the diameter of the setting of the lens, measured across the inner or free circle. In the broadest possible sense the aperture of a projection lens is the diameter of the smallest of its circles, through which the light has to pass. Such circle may be the opening in a stop between the lenses of a combination, or it may be the area of that part of the lens not covered by the brass mounting.

The Focal Distance in Terms of the Aperture

The focal distance of a lens is often stated in terms of its aperture. This practice is very useful for photographers, for it tells them something about the relative working powers of the lens and of its practical qualities. When a lens is described as F 2, it means that its focal distances is twice the diameter of its aperture. If the lens were of one and a half inch aperture, and were characterized as F 3, its focus would be three times one and a half inches, which is four and a half inches.

The usual system in projection nomenclature is to state the focus of lenses directly, as three inches, four inches or whatever the focal distance may be.

Diameter of Projection Lenses

In the photographic world the objective lens of cameras has no standard size. It may be a fraction of an inch in diameter, and that fraction reduced by a stop, or it may be as large as a condenser lens of a projection machine. In moving picture machines there is a pretty close approach to a standard diameter. It is considered that too large a diameter would produce travel ghost or spotty effects on the screen.

In England the standard diameter of projecting lenses is taken as one and forty three sixty fourths of an inch, 1 43/64 in.

Cleaning Lenses

The lenses of a projection apparatus should be perfectly clean. This involves frequent rubbing or dusting off as the requirements may be. It seems a simple matter to clean the polished surface of a lens, but the trouble is not in the cleaning, it is in not injuring the lens in the operation. If a cloth is used over and over again to polish off the face of a lens, it is liable to accumulate dust which may be hard enough to scratch the glass. This is an old and frequently noted trouble of the photographer. He has long been warned not to use the same cloth surface over and over again in polishing his lenses.

Sometimes it is enough to brush the glass off with a soft brush, a camel's hair pencil or a red sable one is excellent. A collection of fine texture old worn cloths, such as cambric handkerchiefs may be obtained and preserved for the cleaning. The rule of never wiping the lens surface twice with the same surface of cloth may be followed pretty well if there are a number of pieces of polishing cloths on hand.

Have them washed from time to time, anyone can do it, and the lenses will be benefitted.

Removing Oil from Lenses

If oil gets on a lens it can be removed with a cloth wet with gasoline or benzine. Two or three wipings may be needed, with a new bit of cloth each time to completely remove the oil from the glass.

Cleaning the Interior of Objective Lens

If the objective accumulates dirt in the inside of the tube between the lenses it will have to be opened by the unscrewing of the lenses. They must then be cleaned with the greatest care, and the interior of the tube must be wiped out thoroughly to ensure the absence of dust from its interior. There is danger to be apprehended of putting the lenses back in the wrong order or with the wrong faces forward. The rule is to face the more convex face of a projection lens towards the screen.

The Central Lens in an Objective

If there is a central lens in the tube of the objective, half way from back to front, do not attempt to remove it. If you succeed in getting it out there may be endless trouble in replacing it, it may go in crooked and the thread of the brass screw holding it may be injured in the attempt to replace it.

Care Required with Lens Mounting Screws

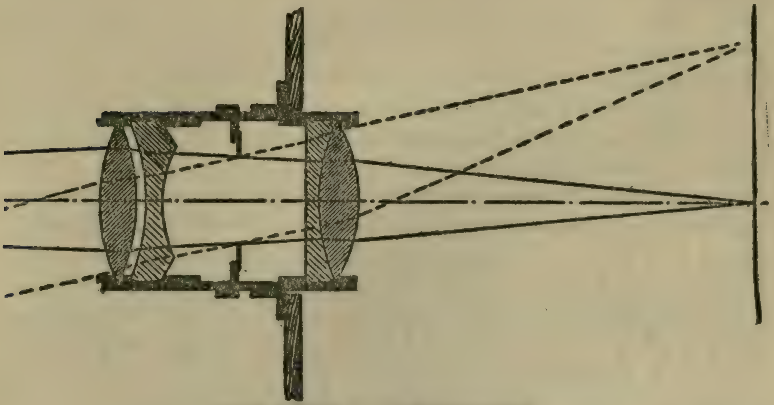
In the mounts of lenses very fine screws are cut in the tube and mounting rings. This is inevitable on account of the little stock there is to work with. Any screw of large diameter compared to its pitch is inclined to give trouble. Often the threads are crossed, perhaps without the operator knowing it, and as he continues to force the piece into place permanent injury may be done to the thread of the tube or mount.

In handling such screws the greatest care must be taken. The feel of the mount as it goes into its place will disclose whether the thread is crossed. The crossing of a thread can be detected in time to prevent injury, if it is watched for. It may take a considerable number of trials to get a fine threaded section of a lens mount in place, as trial after trial fails to find the thread.

One rule, which will work sometimes, but is not infallible, is to turn the piece the wrong way, as if it were being unscrewed; as soon as the right position to commence screwing it in is reached, there will be a slight click. When this is heard the direction of turning must be reversed and the entrance of the thread will be effected. Once the threads have entered, the pieces may be screwed up without fear of damage. It is in the attempts to enter the threads that the damage is done.

The Petzval Objective Combination

J. Petzval was a celebrated scientist of Vienna, from whom the combination of four lenses combined in one set or mount and used extensively as objectives for projection is named. The Petzval objective contains in the front combination two lenses, one of crown glass and the other of flint glass constituting the regular achromatic doublet already described. These two lenses are cemented together with Canada balsam. This doublet is held in the front of a tube, some inches long. At the rear or lamp end of the tube are two other lenses. One is a double convex



THE PETZVAL COMBINATION

lens; this is one next the rear end of the tube. In front of it and spaced a little distance from it towards the center of the tube is a fourth lens, a convex-concave one; this is of little effect except as a corrector of spherical aberration.

STANDARD FOCAL LENGTHS OF OBJECTIVE

The standard run of focal lengths may be taken as from two to eleven inches, changing one quarter of an inch at a time. The focal distances of the lenses do not, however, progress at exactly that rate; in the manufacturing processes it is not possible to work to such a scale with absolute accuracy. The focal length of each lens is measured to one hundredth of an inch, and the length as determined is engraved on the brass mount of each lens.

The exact focus of an objective, which is doing service, and which gives an accurate framing of the picture, should be known and if a new objective is to be procured, it can be ordered of the exact focal length of the one known to do the work satisfactorily.

DEFECTS IN OBJECTIVES

Invisible striae, invisible as far as ordinary observation goes, often make a lens quite unfit for first class work. It is imperfections, which do not meet the eye at first sight, or which may be inappreciable by direct vision, that the lens maker has to be on the watch for. Optical glass is a very special article of manufacture and is judged by stardards quite different from those for everyday plate glass.

Optical glass is very apt to have bubbles in it. These are ineradicable in the manufacturing process. It has been definitely found that they do no appreciable harm. They reduce the light-transmission a little. It is calculated that in the worst cases they do not impair the transmission more than one twentieth of one per cent. The effect of bubbles on the image as projected is entirely negligible.

It is even claimed that a perfectly clear lens is an object of suspicion, as it would probably prove to be made from poor glass; bubbles are almost a criterion of good quality. It is easy to make glass without them, but such glass is not optical glass. One of the leading manufacturers and authorities on projection lenses makes the assertion that "bubbles in the glass prove that it is real high grade optical glass and they therefore constitute the hall mark of quality." In general terms poor glass may have bubbles imbedded in their substances, but good glass always will have them.

Cleaning the Petzval Objective

A lens should give a good image on the screen, and the doing so is the proof of its quality. Contrast, definition, color correctness or achromatism, and a full aperture are to be looked for in a good lens. A slight falling off in definition is inevitable in some part of the screen image, especially towards the edge of the field of view, but there should be no color effects from imperfect achromatism of the objective.

Sometimes a slight reflection from the inner walls of the long tube of the Petzval objective is apprehended, and is guarded against by cutting what is termed an anti-reflection thread on the interior of the tube.

If a Petzval objective has to be opened to get at the interior in order to clean the lenses, the greatest care must be taken to keep track of the different lenses, so as to get each one back where it belongs. A safe piece of advice to give is to tell ambitious operators not to try to take the cemented lenses of the front combination apart. If there is anything wrong with them it is very problematical if an unskilled person will improve matters by melting the cement in hot water, and separating the lenses. If this is done successfully the problem of making a good joint again comes up. The cement between the two glasses must be perfect. It sometimes tends to shrink and impair the transparency of the lenses that it cements. If there is trouble it is in most cases advisable to send it to the factory for fixing.

Overcleaning Lenses

While most authorities lay great stress on the importance of clean lenses, and direct the operator to rub off dust and oil, Colin N. Bennett, an English authority, to whom we refer several times in this book, claims that as many objectives are overcleaned, as are undercleaned. He takes the ground that except for the two exposed front and rear faces, the lens faces should not need rubbing over more than once a month. He says that if there is a doubt about putting the glasses back right, do not take them down at all. The same author very sensibly says that a dirty lens is preferable to a spoiled one. He recommends dusting over the exposed front and rear faces of the lens with a camel's hair brush. If the shine begins to go and the glass seems to require more vigorous treatment, clean it with a silk rag slightly moistened with benzine or pure alcohol. Such is the gist of this authority's recommendation as to cleaning lenses.

FURTHER NOTES ON CLEANING LENSES

If an expensive objective is in use, too great delicacy in treating it cannot be feared. Wiping with a cloth is always rather severe treatment for a high grade lens, unless the cloth is absolutely dust-free and soft.

The glass of a lens is held in its mount by a ring screwed into the interior of the mount. Do not attempt to take this ring out. The unscrewing it may be easily done, although there is always danger of injury to the glass, but the screwing it back may prove very difficult, and once the thread is crossed, and perhaps marred, permanent harm is done.

On no account touch the surface of a lens with the finger. It is sometimes done by those, who know no better; the same class of operator will use an unwashed pocket handkerchief to clean the surface of a lens.

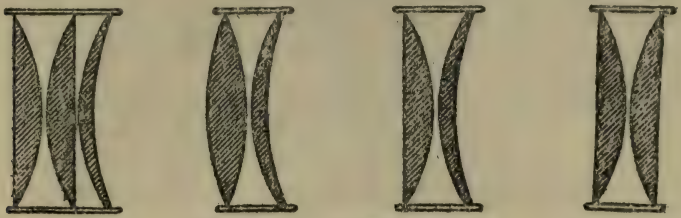
An English lens has been introduced, which has a handle, like the bail of a bucket, whose object is to make the withdrawal of the lens from the tube easy, so that there will be no trouble about cleaning the rear face. It is an interesting addition to the mount.

TYPES OF CONDENSERS

There are, practically, speaking, four types of condensers. It is fair to say that of these the two lens combination in one form or the other is in most general use in this country.

THE THREE LENS CONDENSER

The three lens combination shown in the cut consists of a meniscus lens placed next to the light. Next to this comes a pair of plano-convex lenses with their plane sides outwards. This combination is known as the triple condenser. It is sometimes used in stereopticon work with the addition of a tank of water or of solution of alum in water placed between the two plano-convex lenses. The meniscus lens in this combination is placed with the concave side towards the light.



CONDENSER COMBINATIONS

The three lens condenser is not much used for moving picture work.

The Herschel Condenser

The Herschel condenser comprises two lenses; a meniscus lens placed as in the triple combination followed by a double convex lens.

In stereopticon projection with long focus objectives one form of condenser comprises a meniscus next the light as in the condensers just described, with a plano-convex next to it, the convex side facing the convex side of the meniscus.

The Meniscus Lens in Condensers

In this use of the meniscus lens next to and with the convex face next to the light, there seems to be a feeling indicated, to the effect that the light will be less reflected and wasted at the more advantageous angles at which it strikes the concave face of the meniscus lens. This is perfectly true, but as we have seen, the difference in the amount of light reflected and lost at different angles of incidence in the case of glass, is not very great until very oblique angles are reached.

The double combination of two plano-convex lenses with the convex sides facing is a very usual type in this country. Its action is to receive the rays from the lamp at advantageous angles, as far as that amounts to anything, and to bring the diverging cone of rays into parallelism, as they leave the first lens.

This is the general action; often, however, the rays still diverge a little after leaving the first lens.

The light rays next are caused to converge after passing through the second lens.

In practice it is quite usual to have plano-convex lenses of different focus in the same condenser; a six and a half inch focus lens next the light and a seven and a half inch focus lens next the objective is quite usual.

The triple combination is claimed to pass more light to the screen than the others, but is considered objectionable as the meniscus is apt to be cracked by the heat of the lamp. The reason is that it has to be placed very close to the lamp to get correct action.

The Herschel condenser is said to be excellent for long focus objectives, and for short focus objectives the double plano-convex combination is said to be the better.

POSITION OF THE CONDENSER

To give a different point of view in any matter of adjustment is often of interest. The following is the system of determining the position of the condenser behind the gate as given by an English authority, Colin N. Bennett, F. C. S.. F. R. P. S. He states that for four and a half inch diameter condensers the distance is double the focus of the objective lens with one or one and a half inches added. If the objective is of over five inches focus, the theoretical distance may be shortened an inch or two, as a "convenient compromise." He goes on to state that the distance between the condenser and the gate is not decided by the focus of the condenser at all, but is wholly decided by the diameter of the condenser and by the focus of the objective. For four inch condensers this author adopts just double the focus of the objective as the theoretical distance.

HEAT PRODUCED BY CONDENSERS

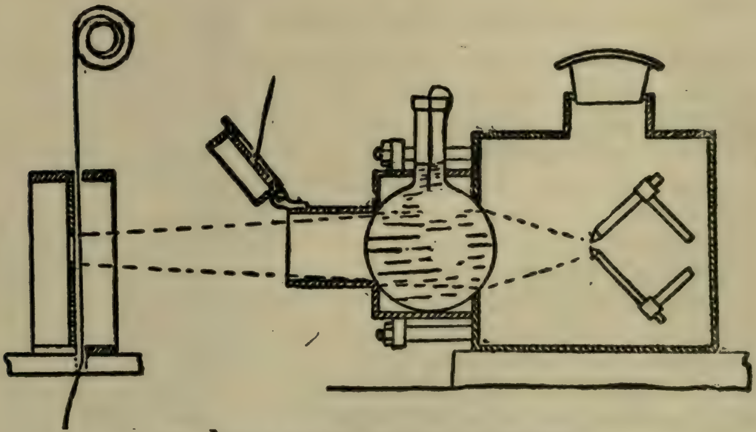
The heat produced by the condenser rays upon the film is very great. The rapid motion of the film is what saves it from igniting. In the early days of the art Lumiére, the great French manufacturer, realizing this employed a spherical flask of water as a condenser. In it, near the surface, he suspended a bit of coke to secure quiet evaporation of the water. A solution of alum is better than plain water for the exclusion of heat. The cut shows the old-time Lumiére lantern with its water condenser.

At the present time trouble is experienced with lantern slides, owing to the heat. If the projections are kept on the screen too long they are liable to crack. If they do not crack during projection, there is danger of their doing so after removal from the slide holder, owing to the cooling effect of the air.

This trouble is so frequent with arc light projection, that it is necessary to give a very short period of projection to a slide, a half minute or less on the screen is all that is safe.

Water Tank in the Condenser System

To cope with this trouble a tank of water, or solution of alum is sometimes placed between or in front of the condenser lenses. This cuts out a great deal of the heat and makes the projection comparatively safe. One disadvantage is that the space taken by the water tank is inconvenient; another is the absorption and reflection of a certain amount of light.



LUMIÈRE'S EARLY WATER CONDENSER

Heat-Absorbing Glass in the Condenser System

A special heat-absorbing glass is sometimes placed between the condenser lenses. This is supplied in the form of a disc to fit in the mount, and is claimed to be the best and most convenient protection from the heat in question, that has as yet been devised.

SPHERICAL WATER LENS AS CONDENSER

The use of a spherical vessel of water for a condensing lens seems a primitive contrivance. It was done, however, and it had a second function, whether calculated upon or not, and that was to keep the heat from the lamp down to some extent at least. For projection of lantern slides we often find plain parallel sided water tanks with plane glass sides shown. Sometimes to increase the effect alum is dissolved in the water. Some recent investigations and experiences with the reduction of the heat incident to projection have led to some curious statements. It is claimed that warm water proved a better agent for reducing the heat from the lamp, than did ice water. The use of alum solution was said to have produced no better results than when water alone was employed.

GLASS PLATES IN CONDENSER TANK

Plane glass plates were experimented with, and it was here that an interesting fact was elicited. A set of plates immersed in the tank filled with water were found to cut off the heat so as to keep it too low to do any damage even for many minutes of exposure. The glass had plane surfaces, and were spaced apart in the water of the tank.

The full description does not seem quite coherent, but there is at least an interesting subject for investigation suggested by the experiments cited. If without reducing the light and without introducing any additional troubles in the operation of the projection apparatus, a way of avoiding the heat which the film has to stand could be found it would certainly be a great advance. In early days the effects of a blast of air was tried but that like the water tank is pretty well forgotten. Air in motion operates so well on air-cooled internal combustion engines, that it would seem well adapted to cool the gate and the film in the aperture.

LOSS OF LIGHT BY REFLECTION FROM CONDENSER SURFACE

Although, as we have seen, there is little difference in the percentage of light reflected from the surface of a lens, at different angles, within the limits of the size of lenses used in practice and of their focal lengths, yet there is a feeling that oblique rays, those falling on the lens face near the periphery, are reflected and lost in larger proportion than those impinging more nearly perpendicularly on the end, near to the center. Really there is but little difference.

Some condensers contain three lenses. The one nearest the light is a meniscus, with its concave side towards the light. Next are the two plano-convex lenses, with convex faces inwards, just as in two lens condensers. This gives a better average of angles of impingement, than does the flat surfaces of an ordinary condenser lens.

Corrugated Lens in Condensers

Another form of condenser is made with a corrugated lens next to the light. This is what is called from the inventor, an eminent French scientist, a Fresnel lens. It is a series of annular prisms, and it will be seen that the light falls on the faces of these lenses in a very advantageous direction.

Small Area of Light Desirable

Condensers are formed to condense the diverging cone of rays radiated from a point of light. In reality the light always has a real size; it never is a point, so condensers work a little at a disadvantage in this respect. The effort of the day is to find a lamp with as small an area of light giving surface as possible. In the section devoted to lamps this question will be taken up, and we shall see how the more advanced types of lamps have small, intensely bright areas of light giving carbon, if arc lamps are in question. In incandescent lamps the filament is wound as close as possible so as to effect this concentration of area.

Lining Up and Setting Condensers

The crater or center of illumination of the lamp is to be placed within the principal focus of the lens of the condenser next it, in two lens condensers, when the rays are to diverge between the two lenses. This construction is quite frequent, the rear lens, the one next the lamp being of shorter focus than the front one. The effect of this is that the light from the condensers comes to a focus in front of the condenser, beyond the principal focus of the front lens. When the two lenses are of identical focus, the rays of light between them are parallel so that the light, which passes through them, comes to a focus at the principal focus of the front lens.

If the light between the lenses of the condenser diverges, loss of light is avoided by keeping the condenser lenses close together. It follows from this that if a tank of water is to be kept between the condenser lenses, a divergence of the light between them is inadmissible.

CONDENSERS AND THE HEAT OF THE LAMP

Condensers are troubled by the heat of the lamp; it is not alone the film, which suffers. It is suggested by Gage that a condenser, whose rear lens is made of heat resisting glass is a desideratum. There is no doubt that a glass rich in silica would tend to give such a condenser, but whether optical glass could be made from such a mixture is a question.

The heat question is taken care of in some constructions by spring mounts for the condenser lenses; in other constructions heavy metallic mounts are used to absorb and in some measure reduce the heat.

One rule applying to stereopticon work is that the objective and condenser should have approximately the same focus. This rule seems arbitrary and would never apply to moving picture projection.

LINING UP THE OPTICAL SYSTEM

The constructors of projecting machines are supposed to send them out in line as regards the lens system. The requirements are very simple. Everything should be in line and square or parallel as the case may be. The requirements speak for themselves.

The mount of the condensers will ensure their parallelism with each other. A straight line from the center of the front lens of the condensers to the center of the aperture should be perpendicular to the face of the condenser. In some cases the space between condensers and aperture may be so open that the squaring can be tested by the means to be described. A piece of pasteboard is cut at one end perfectly square across, and of the width of the condenser. A straight line is drawn through its central axis, perpendicular to the end. The length should be such as to reach from condenser to aperture. The piece of pasteboard must be placed across the center of the condenser surface, horizontally and vertically, or at any other angles. If the setting is square the pencil line will come to the center of the aperture for each position.

Another way is to take out the condensers, and to put a stiff piece of cardboard, which exactly fits in their place, into the mount. A hole is to be made in the center of the pasteboard, and through the hole a string or thread is passed, knotted at the back to prevent it from passing through the pasteboard. The thread is stretched through the center of the aperture, and if the condensers are square in their setting, the string will be square with the surface in the pasteboard. Its squareness can be tested with a draughtsman's triangle or any improvised square.

The aperture plate should also test absolutely square with the thread. The next thing is to take the objective lenses out of their tube and passing the thread through the tube and stretching it, so that it will be in the center of the circle of the tube, see if it is still central with the gate or aperture.

Some advise fastening the thread to the upper carbon. This has the advantage that by moving the carbon by the hand screws, the thread can be brought to the center of the condenser opening. This must be done after the string is stretched to the center of the gate or of the tube of the objective.

The way of testing the setting of the different lenses in any projection apparatus will depend on its make. It is always possible to arrange some system by which the parallelism and squaring of the parts can be tried.

When all is found to be square and correct the lamp mounting may be tried out. This can be done optically. The lamp is lighted and it is so placed as to project itself on a card placed in the gate. It is shifted about until the projection comes exactly in the center of the opening. The lamp is then moved back. This gives it a shorter conjugate focus. This conjugate image is received on a piece of cardboard, and its height from the base of the apparatus is measured. It should be the same as was the height of the image at the aperture. This test is to determine if the bearings of the lamp are parallel with the base of the machine, and if they are at right angles to the plane of the condensers.

The arc light is characterized by constant change of position of its crater, so the last test should be made quickly and with due regard to this quality of the arc. If it is possible to substitute an incandescent lamp with concentrated filament for this test, it would be well to do so. As the lamp is under constant watching, if it is an arc lamp, and is arranged for adjustment by hand during the progress of the exhibition, the accuracy of the position of the lamp does not play an important part in the operation, because it is readjusted for every lighting, and it is supposed to be shifted about until in proper position by the operator. If the lamp is an incandescent lamp, its support and bearings must be absolutely true, as it is supposed to be right to start with, and to go back into its correct position, without hand adjusting. The case is quite the opposite to that, which obtains with the changing arc lamp.

Adjusting Lamp for Condenser Position

There is another point to be taken into account. By shifting the lamp about, using the adjusting screws provided for the purpose, errors in the setting of the condensers can be easily compensated for. As all the tests for correct setting of the lenses depend on scale measurements, they are not very accurate. It is therefore a fortunate circumstance that so much can be done by adjusting the position of the lamp, moving it to right or to left, and up or down until good condenser action is obtained.

Importance of Lining Up the Objective

The lining up of the objective is quite important. Here not so much can be done with the lamp adjustments; the objective should be right to start with. By changing the lamp's position, if necessary, a correctly located cone of rays from the condenser can be obtained, and the condenser focus can be placed accurately upon the face of the rear of the objective. But beyond this the condensers and the lamp cannot go; the objective must do the rest. If the lamp is out of place the screen will show it by shadows on the disc, to right if the lamp is to the left and so for other misplacements. The disc will tell what to do with the lamp. But for it to be able to do this the objectives must be in position and in line.

Different Foci of Lenses

It is the custom to assign several foci to a lens. There is one, however, which is by far the most important one, and one on which calculations as to the magnifying power at different throws or distances should be based. Taking the general rule to the effect that the size of the projected picture on the screen will be equal to the size of the aperture multiplied by the throw and divided by the focal distance of the lens everything should be referred to the true focus of the lens.

If we take the length of throw it can be measured from the screen to the surface of the film, which is to the aperture plane. If this is done then a correction has to be introduced in the calculation. Instead of multiplying by the throw thus determined, the focal distance of the lens has to be subtracted from it, and the difference between the throw as measured to the plane of the film or of the aperture, and the focal distance has to be taken for the multiplier. This is the course often followed and it is a very poor way of getting at a result. The idea of subtracting the focal distance from the throw has got so firmly fixed in the minds of many, that the subtraction appears in formulas, where it should not. It is far simpler and far more intelligible to do it rightly.

MEASUREMENT OF LENGTH OF THROW

The length of throw is properly measured from the surface of the screen to the center of the lens. This is the optical center. It is the part of the lens, whose distance from the principal focus is equal to the focal distance of the lens.

OPTICAL CENTER OF COMPOUND LENS

Thus if a distant object is projected on a sheet of paper with a lens of known focus, the focal distance measured from the paper back to the lens will locate the center of the lens on the mount. The tube of the objective may be several inches long. On it the focal distance will be found inscribed or engraved. Then taking this distance in inches and perhaps in hundredths on an inch, measure back on top of the lens tube. Mark the point with a lead pencil, if you do not wish to scratch the mount. This is the center, and gives the proper place from which to measure the throw.

To make the measuring simpler some other place may be measured to on the machine. For instance the front of the lens would seem the most convenient. If this is done then to this distance should be added the distance from the front of the lens to its optical center. The optical center is the true basis for measuring the throw. It is no matter how the result is reached, as long as the length of throw is the distance from center of lens to screen.

THE BACK FOCUS

The back focus of a lens is a figure often referred to and used in discussing problems of projection. This is really an arbitrary figure, for it does not give anything except an easy way of putting an object in the focal plane or a given distance back or forward from it. It is the distance from the surface of the rear lens of the objective to the plane of the focus. If we refer to the center of the lens, it is the focal distance less the distance from the center of the lens to the rear surface of the rear lens.

While it is certainly an easy surface to measure from, as it is so accessible, it is a poor practice to use it as a base of measurement. This use of it implies the placing the end of a rule against it. As far as possible no such object should be allowed to touch a lens as there is always danger of scratching it. If the surface of the lens must be measured from, a piece of clean paper should be placed between it and any rule or stick used to get the distance.

THE EQUIVALENT FOCUS

The equivalent focus is often taken as the distance from the focal plane to the center of the lens tube. This again is only an approximation to the true focus of the lens. It is a figure constantly referred to. It is not of much real importance except as an approach to accuracy.

THE FOCAL PLANE

The focal plane of a lens is an imaginary plane or flat surface at right angles to the line from center of the rear lens to the focus of the lens. In a perfect lens all objects in this plane would be perfectly in focus. This means that all the rays of light from all parts of this plane, falling upon the surface of the lens would be so refracted that they would emerge on the other side of the lens in parallel lines. Any distant object would have its image focussed on some part of the focal plane.

FINDING THE FOCUS OF A LENS

The simplest way of finding the focus of a lens is perhaps to focus a distant object through it and measure the distance from the focus to some part of the mount. The lens is then reversed and the focal image of the distant object is produced again, but this time with the lens reversed, so that the image is produced by light coming through the lens in the reverse direction. The distance from the focus to the same part of the lens as before is then measured. The half sum of the two distances gives the focus.

There is another way of finding the focal distance, not as simple but instructive. An aperture of accurately known size, or any other object of known dimensions, is projected on a screen or on a sheet of white paper. The three things, lens, paper and lens, are shifted about until a projection is produced on the sheet of paper exactly as large as the object itself. It is here that the difficulty comes in; the two must be of exactly the same size. When the position of the three has been secured, which gives this result, the distances from image to paper will be four times the focal distance of the lens, and the half way point between the paper and object will be the center of the lens.

SIZE OF IMAGE ON THE SCREEN

The size of the projected image of an object varies with its distance from the lens. To produce a magnified image the object must

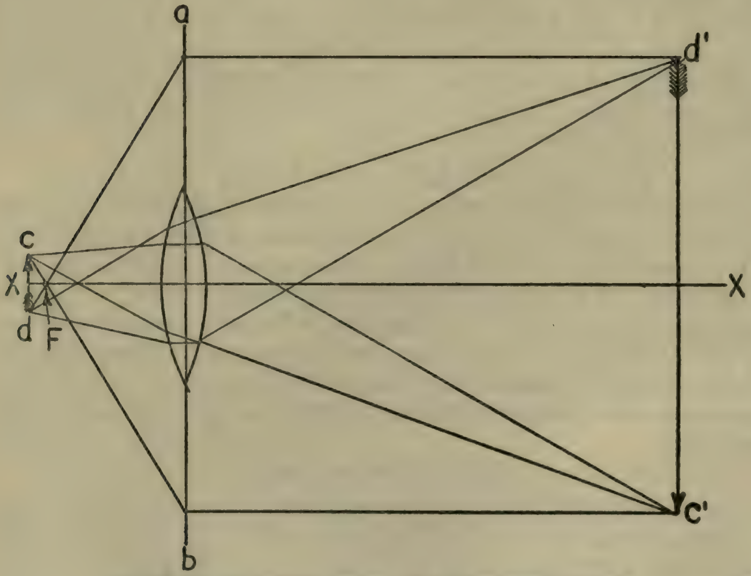


DIAGRAM SHOWING SIZE OF PROJECTED IMAGE

be between the principal focus and double the principal focus. Thus if a lens has a focus of 4 inches, a film picture must be over four inches from the lens to give a projection larger than itself. Now the question comes up of how far back of the principal focus, or better principal focal plane, it must be to produce a projection of any given size.

This is found by a very simple geometrical construction. In the diagram let *c, d* be an object to be projected. Let F be the focus of the lens. If from one of the extreme points of the object, which lies back of the focus, a line be drawn to intersect the line, *a, b* drawn through the center of the lens and parallel to its face, the distance from the intersection in question to the center of the lens will be one half the size of the projection. The distance XF is the distance of the object from the principal focal plane. This we wish to determine. By simple geometry the triangles, *d*F*c* and F*ab* are similar, and Ff is equal to one half the size of the object. We then have the proportion:

X F : Focus : : Frame : Image

in which Af is the unknown quantity. Suppose the focus of the lens was 5 1/2 inches, and that it projected a 15 foot image of the frame of the standard diameter on the screen. 15 feet equal 180 inches. In the proportion we will substitute for Focus and for Image, their values, and the focus of the lens being 5 1/2 inches. The proportion then reads:

x : 5 1/2 : : 29/32 : 180

and solving the proportion, we find x=0.028 inch. The film must be nearly three one-hundredths back of the principal focus. This quantity is so small that is is clear why the required focus of a lens can be calculated on the assumption that the film is at the principal focal plane. The distance of the film back of the focal plane is so slight that it can be disregarded in any but the most accurate calculations. There is no reason why it should not be taken into the calculation if so great a degree of accuracy is essential.

SIZE OF SCREEN IMAGE

A very simple rule for determining this figure is given by Colin N. Bennett in his book on kinematography. It is based on the fact that the diameter of the projected picture will bear to the corresponding diameter of the original on the film, the ratio of its distance from the center of the objective to the distance of the film picture therefrom. He takes the gate diameter as one inch, and divides the distance of the screen in feet by the focal distance in inches. The quotient would be correct for a diameter of one inch; it is then to be corrected by multiplication by the fraction expressing the real diameter of the gate opening which is the diameter of the film picture as projected.

EXAMPLE OF CALCULATION OF SIZE OF SCREEN IMAGE

Let the gate opening be 29/32 inch, and the focus of the lens 5 inches and the distance of the screen from the center of the lens be 60 feet. First divide 60 by 5 giving 12 feet. This would be correct for a one inch gate. Then multiply 12 by the fraction 29/32 and we obtain 10.87 feet or a little over 10 feet 10 inches.

It seems incongruous to divide feet by inches. The operation could be done equally well by dividing the same quantities, expressed in inches by their ratios, into each other as done above, multiplying by the diameter of the gate, expressed as it always is in inches or rather in fractions of an inch. This gives the diameter of the picture on the screen in inches, and can be reduced to feet by dividing by twelve. The trouble of this division is avoided by the dividing of the feet by the inches in what at first sight may seem an incorrect way of calculation.

Thus: 60 feet is equal to 720 inches. Dividing this by 5, which figure is the focal distance of the objective in inches, we obtain, 144 inches as the diameter of the screen image in inches, and this is equal to 12 feet as before, and 12×29/32 gives 10 feet 10 inches.

Another way of calculating the focus of an objective for a given throw and a given size of picture on the screen, is to divide the throw by the diameter of the screen picture desired, and to multiply the diameter of the opening in the aperture plate or gate by this quotient. The result will give the focal length of the objective required in inches.

Assume a throw of ninety nine feet, and that a diameter of screen picture required is sixteen feet. If we divide 99 by 16 we obtain as quotient, 6.1875. Then multiplying the aperture, which we will take as 29/32 inch, which is the standard now, the product is 5.6, almost exactly.

One curious thing, which has been observed, is that errors in the measurement of the distance from machine to screen are apt to be made. One authority says that an error of as much as fifteen feet in the throw has occurred.

One of the leading manufacturers of objectives and condensers asks to have the length of throw imparted to him, when he will calculate the focal length of lens required for the desired picture. Then if the throw has been incorrectly given, the picture will be projected of the wrong size. If the size of the projected picture is then also given, the proper lens can be calculated.

This is a roundabout way of getting at the focus of the objective.

Example of Indirect Calculation of Focus of a Given Image

Suppose a sixteen foot picture is desired and that the lens has been ordered as for a one hundred foot throw, while the real throw is only ninety feet. The manufacturer would send a five and three quarter inch focus lens. This lens, when tried at the real throw of only ninety feet would give a picture a little over fourteen feet in diameter. This figure is calculated by multiplying the product of the throw by the aperture diameter, 29/32 inch, and dividing the product by the focal length of the lens.

The lens would have to be exchanged for one of five and one tenth inch (about). This figure is obtained by multiplying the size of the picture projected on the screen by the focus of the lens producing it, and dividing by the required diameter.

The methods used for determining the focus of an objective which have been applied above are based on the supposition that the film picture is placed so near the principal focus of the objective, that the calculation may be based on the exact focal distance. It should however, be based on a slightly greater distance, for if the film were at the focus there would be no projection; the rays would leave the objective parallel to each other.

Various Methods of Calculating the Size of Screen Image

This is said with a reservation. It is convenient to treat the projection of a transparency, such as a film picture, as if it were a real object projected by reflection of diffused light from its surface. As the film picture is a transparency and as the rays, which pass through it are converging the case is somewhat different, and is discussed elsewhere. But here the rule for determining the focal length of an objective and the other rules, which may be called variations of it will be given. They may also be expressed in formulas for those, who work by formulas.

(1) To determine the focus of an objective lens to give a picture on the screen of a given diameter at a given throw or distance; divide the throw in feet by the desired diameter in feet, and multiply the diameter of the aperture by the quotient. The result will be the focus in inch measurement.

(2) To determine the diameter of a projection on the screen given by a lens of known focus at a given throw; multiply the throw in feet by the aperture in inch measurement, and divide by the focal length.

(3) To determine the focus of a lens, by the size of picture projected at a known throw; divide the throw by the diameter of the projected picture and multiply the aperture by the quotient. This is a good way of measuring the focal length of a lens.

To express the above in formulas, call the throw, T; the diameter of the projected picture, D; the focus of the lens, F; and the diameter of aperture, A. Then for the rules, 1, 2, and 3, we have:

$$(1)\ F = \frac{T}{D} \times A. \qquad (2)\ D = \frac{T}{F} \times A. \qquad (3)\ F = \frac{T}{D} \times A.$$

Examples of rules (1) and (2) have just been given. An example of rule (3) will be given here.

A lens is found to project the standard aperture of 29/32 inch on a screen at twenty feet distance, with a diameter of four feet. What is the focus of the lens?

Divide the throw, 20, by the diameter of the projected picture, 4; the quotient is 5. Multiplying 29/32 by 5 gives 4.526, the focus of the lens.

It may be easy to substitute an exact inch aperture for the focal measurement by this method to avoid fractional diameter of the aperture entering into the calculation.

This method can be carried out in a room with any reasonably strong source of light, and with a hole cut in a card as the aperture. The card must be brought as close to the lens as possible, so long as a sharp image of the aperture is produced. The largest image must be projected to make the method correct. The image must be a true projection.

THE BAUSCH AND LOMB RULE FOR CALCULATING THE FOCUS OF OBJECTIVE

The Bausch and Lomb Company use as a practical method of determining the size of the image the simple rule given here. In the preceding pages, the rule given differs a little from this one, but neither is to be regarded as strictly accurate, as we shall presently see. They say: The size of image can be determined by multiplying the difference between the distance from lens to screen and the focal length of the objective, by the width of the aperture plate, and dividing the product by the focal length.

Let l be the projection distance, 100 feet (1200 inches); s, one side of the film picture aperture; f, the focal length of the lens, 8 inches, then we have the formula (in which d is the size of the image) $d = s\dfrac{(l - f)}{f}$

Substituting for the letters their known values, we have

$$d = \frac{.906(1200 - 8)}{8} = 135 \text{ inches} = 11 \text{ ft. } 3 \text{ inches.}$$

For determining the focal length multiply the width of the film aperture by the distance from lens to screen and divide the product by sum of the width of the image and the width of the film aperture.

Thus we have the formula, $f = \dfrac{s \times l}{d + s}$. and substituting their

measured correctly.

values as before, $f = \dfrac{.906 \times 1200}{135 + .906} = 8$ inches.

THE GUNDLACH-MANHATTAN RULE FOR CALCULATING THE FOCUS OF OBJECTIVE

The Gundlach-Manhattan Company write as follows:

An accurate rule for determining the focal length of lenses for a given throw and size of image involves a very complicated equation, which we will not go into, as we think you merely want a simple rule for this purpose which is reasonably accurate and which we use ourselves.

The rule is to divide the distance in inches by the number of magnifications to the foot, which gives a multiple of 13.24; for example, the magnification for a 10 foot picture is 132.40 and for a 16 foot picture is 211.84. In practice we ignore the decimal and for a 16 foot picture we would figure on 212 diameters. In any case the distance is always an uncertain factor because it is seldom measured correctly.

The focal lengths of lenses for projecting lantern slides is figured on the same basis. The multiple for a mat opening 2 11/16, 2 7/8 is 4.17, and this multiplied by the width of the picture in feet will give the total number of diameters.

The above may be explained to make it clearer to the reader. The distance is the distance from the screen to the center of the lens. This is not the distance from the middle of the lens tube but to the optical center of the combination, taken longitudinally. The multiples are obtained by dividing twelve inches by the width of the gate or mat, as the case may be. Thus $12 \div \frac{29}{32} = 12 \times \frac{32}{29}$, which gives as the quotient 13.24. Now take the sixteen foot picture cited. Its width is to be multiplied by the magnification per foot. This is 13.24, as we have seen. Now we must multiply 16 by this multiple, which gives the figure cited above, 211.84. To get this magnification the focus of the lens must be equal to the throw in inches divided by 211.84.

Let the throw be 127 feet. This quantity multiplied by 12 gives 1,524 inches. It is divided by the above number, 211.84; performing the division we get 7.19 inches as the focus of the lens to produce a sixteen foot projection at a throw of 127 feet. Had we thrown out the fraction and used the figure 212, the result could have been almost exactly the same, 7.188 inches focal length of the projecting lens.

The great complication of the equation giving the theoretically accurate focus of the projection lens for stated magnification is due to the fact, that the film is not at the focal distance of the lens. It is always a little back of it. Otherwise there would be no projection. All the practical calculations are founded on the assumption that the film image lies at the focal distance of the lens, something it does not and cannot do and be in focus on the screen.

But the film is always so nearly at the focal distance, that no error of any amount is introduced by the assumption referred to. The reason the film is so nearly at this distance is because the magnification is so great. The film picture is smaller than a postage stamp, and it is magnified to ten or fifteen feet in diameter. To produce such magnification it must be very near the focal plane.

The method given by Bausch and Lomb, however, does take this slight difference into account and where their formula is used the calculations will be absolutely accurate providing all measurements are correct.

Basis for Calculating Objective Focus

The approximate rule followed to determine the focal of lens to produce a picture of a given size at a given throw is based on the supposition that the aperture is at the focal plane; that the focal plane and the film in the aperture are one and the same. This is not true. Yet under the conditions of motion picture projection it is so nearly true that the simple rules based on that supposition are near enough the truth for practical calculations. The following factors in the case should be understood.

If an image lies in the focal distance from the optical center of a lens, no projection will be obtained. So if a projection machine is fitted with a lens of six or seven inches focus, a picture placed respectively at six and at seven inches distance respectively from the center of the lens will not focus on the screen, no matter how near or how far the screen may be from the center of the lens. If with the six inch lens in the machine the film is placed at seven inches from the lens center, a projection will be produced. If the seven inch lens is in the machine, then to obtain a projection, the film must be more than seven inches from the center of the lens.

General Rule for Relations of Focus of Objective and Image

The following is the general rule for the relation of distance from lens and focal relation to projection.

1. An object placed at the infinity focus of a lens will not be projected. The rays of light emanating or reflected from it will pass through the lens and will leave it in parallelism with each other.

2. If the object is placed within the focus of the lens, nearer to it than its focus, again no projection will be possible. The rays of light passing through the lens from the object will emerge in diverging lines, like a truncated cone, whose smaller end is the front face of the lens.

Thus if a light is placed in the focus of a lens, the light will pass through the lens and give a cylindrical beam of light, uniform in diameter for its whole length. If on the other hand the light is brought nearer than the focus, the light will pass through the lens and the rays will diverge and spread.

3. If an object is placed back of the focus of a lens its image will be projected. It matters not whether it is near or far the projection will be produced.

4. The farther the object is from the focus of the lens the smaller will its projected image be.

5. The farther the object is from the focus of the lens the nearer to the lens will its projected image be.

6. If the object is at double the focal distance of the lens from its center, the projected image will be at the same distance from the center of the lens, on the other side of it, and it will be of the same size.

PRACTICAL RULE FOR SIZE OF IMAGE ON SCREEN

It will be understood that the above summary of rules refer only to projecting lenses, and that by the center of the lens is meant the imaginary point near the centre of the lens, from which the focal distance is measured.

We now come to another practical rule. It is impossible to project a picture unless it is back of the infinity focus of the projection lens or objective. To determine the size of the projected image the diameter of the picture is to be multiplied by the quotient obtained by dividing the distance of the center of the lens from the screen by the distance of the picture from the same plane or point.

To determine what this distance must be we must know the amount of magnification of the image required. Here is the approximate rule.

The distance from the infinity focus to the picture is obtained by dividing the focal length of the lens by the number expressing the magnification required.

Suppose the lens of the objective has a focal length of ten inches, and that the picture is to be magnified one hundred times. Then ten inches is to be divided by one hundred. This gives one-tenth of an inch. The film in the aperture must be one-tenth of an inch back from the infinity focus of the objective, or 10 1/10 inches from the optical center of the lens.

Taking the standard width of 29/32ds of an inch for the picture one hundred times this width is a little over ninety inches, 90 6/10ths inches, or about seven feet six inches.

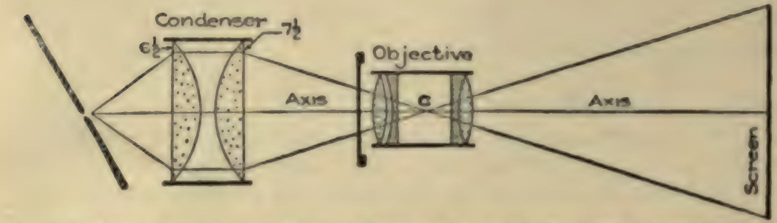


DIAGRAM OF OPTICAL SYSTEM OF A PROJECTION LANTERN

To find the distance from the screen, the distance of the picture from the center of the lens has to be multiplied by the magnification required. This distance is ten and one-tenth inches, or one hundred and one tenths. Multiplying this by one hundred gives one thousand and ten inches, or eighty-four feet two inches for the throw, measured from the optical center of the objective.

If the focal lengths of the lens had been used in the calculation instead of the distance to the film the result would have been eighty-three feet four inches for the throw.

The rule thus given, as a nearer approximation to the truth, is for practical work or refinement, which is not needed. For the picture will at such distances be projected of larger size than seven feet six inches in diameter; it will therefore be placed still closer to the objective, which will bring the regular rule still closer to the truth.

But the best rule of all is to let the manufacturer of the lens calculate the focus you require for a given throw and magnification of the image.

Geometrical Treatment of Size of Screen Image

The preceding geometrical treatment of the possible size of the projected image is interesting and makes the subject comparatively simple. It has to be taken with certain acceptations, such as the assumption that the lens has no aberration of any kind. The assumption is made that the lens brings all rays falling on its face accurately to a focus if they fall in the proper direction, which is parallel to each other and perpendicular to a plane passing through the centre of the lens at right angles to its axis. The diagram on page 157 will make all this clear.

CHAPTER IX

PROJECTION BOOTHS

THE government authorities of the different states have passed laws affecting the presentation of motion pictures, designed to protect the audiences against danger incident to the inflammable material of the films. There is a sort of coincidence about it that so inflammable a material had to be used at a high temperature, and that literally an interruption in the motion of the film, unless some measure of protection were adopted, would almost certainly catch fire.

The measure of precaution is the dropping of a metal shutter back of the film, between it and the lamp. This is done automatically if the machine stops running. It is a hinged plate of steel or metal, which if left to itself will fall down over the back of the film, and cut it off from the rays of the electric arc or incandescent lamp. The first named, the arc lamp, is generally taken to be the hotter and most dangerous in this regard. If the safety shutter is held up and the light allowed to be condensed upon the motionless film by the condensers, as it is condensed in running the machine for projection, the film will pretty surely catch fire in a few seconds.

THE BURNING OF FILM

The burning is not spectacular. It is rather a gradual combustion, with little flame. The film is held in the frame of the gate at this place. It is surrounded and has its edges clasped or enclosed by metal. All this exercises a cooling effect. There is a plate surrounding the gate, the special functions of which are indicated by its name; this is the cooling plate. All this operates to moderate the intensity of the combustion in the exposed part of the film. But the arrangement generally does more than this, it tends to and generally does limit the part of the film, which burns to the portion untouched by the metal. An oblong hole the size of the picture is generally burned out of the film. This applies when the film is motionless. It is easy to see that if the film caught fire while the machine was in the rapid motion incident to projection, the film passing across the gate at the rate of a foot a second, the fire might be carried outside the limits of the gate. Once it caught fire outside the gate, it might reach the magazine and a rather serious fire would result. It would be serious in its effect upon the machine, which might suffer considerably.

Chemical Relations of Film Material

In its chemical composition, the film is related to gun cotton, and is a semi-explosive. The knowledge of this fact has inspired very definite legislation to protect the community from accident. There are regulations affecting the carrying of films, requiring special fireproof boxes, although there is hardly any danger of their igniting unless in the lantern. Many attempts have been made to produce a successful fireproof film, and more will be said of this later. The fact remains that the majority of films, practically all of those used in public exhibitions are of the inflammable composition. The danger is not only that of setting the building on fire; there is the attendent danger of panic of the audience. This is complicated by the fact that almost invariably the audience, in a rush to escape in the obscurely lit hall, would have to pass directly under the location of the burning film. An audience in a panic is not to be reasoned with; it is possible that some one might have the presence of mind to turn up the lights, but all such things are conjectural. Again the general knowledge of the stringent laws, affecting films, tends to make the public afraid of them. The result of the passage of the laws in question, is that the theatre is admirably protected against fire from the film; if a conflagration does occur in a motion picture house, its origin is to be sought anywhere except in the projection booth. The film will never set the building on fire. But it may be the source of a disastrous panic.

State Laws Affecting Projection Booths

The laws of different states read a little differently in regard to the construction of these rooms. Their construction is specified in some states with considerable minuteness of detail. The general idea is to enclose the lamp and film in a fireproof room; to have the room arranged so that in case of fire it can be absolutely shut off from the sight of the audience, and that this shutting off should be automatic in case of a real fire. There have got to be apertures in the front facing the backs of the audience. The operator has to watch the screen through one opening. If there is only one machine there is an aperture in the wall of the room for it to project its pictures through. This gives a minimum of two openings. But if there are several lanterns to be installed, there will be at least two openings for each one.

For each opening a sliding or pivotted cover is provided. This is so constructed as to tend to fall and close the opening it belongs to, but it is held above the opening in suspension by some device, which will be susceptible of instant release so that it can fall and close the opening. It must not be only one shutter so arranged. The closing appliances must be such as to act upon all the shutters at once, for there would be no object in closing only one.

AUTOMATIC CLOSING SHUTTERS

Various arrangements for effecting the closing of the shutters of the projection room have been employed. Some authorities recommend the use of pieces of film, to act like fusible alloy links in automatic sprinkling systems, so much advocated by the insurance companies. The shutters are to be held up by strings or wires, and somewhere in the system a section of the wire is to be replaced by a strip of film. Then in case of a fire it is assumed that the easily ignited film would burn causing a break in the suspension, and the shutters would automatically be released and would fall. Strips of fusible alloy may be used in the same way. Generally the drop will be effected by the weight of the shutters.

In one typical arrangement the shutters work up and down in slideways affixed to the front wall of the room. Each is held up by its own chain, which are attached to an iron or steel roller, sometimes called a pipe. The chains pass around this a number of times. The weight of the shutters tends to turn the roller. If it turned the shutters would fall as the chain was paid out from the rotating roller. The roller is prevented from turning by fusible alloy links; if one of these melts the roller will be free to turn and as it does so, all the shutters will drop over their respective openings at once. It is for shutters supposed to close automatically in case of fire, that sections of film are advised to be used to operate as the fusible links are intended to here.

Inadequacy of Automatic Booth Shutters

The trouble with all such arrangements is that the fire or conflagration has to make considerable progress before they can be expected to operate. It takes a degree of heat to melt the most fusible alloys, which would not be attained in the room until the fire had made considerable progress. It is even a question if in a properly constructed structure, the heat due to a burning film would ever be enough to melt an alloy or to inflame a strip of film, so as to release the shutters. But when the law requires and specifies the automatic feature it must be provided.

From the point of view of the owner of the apparatus two things are most important. The first is to have no fire. If such occurs the melting of fusible links or the burning of a bit of film, are not adequate protection. The shutters should be so arranged that they can be instantly released by the operator. A handle connected with the suspension system, a touch applied to which will release the shutters, should be provided. It is a matter of conjecture just how long after a fire started before a fusible alloy link would melt or a strip of film would ignite. There is no question that an operator could get the shutters closed quicker by far than either of these arrangements.

Opposition to Automatic Fire Shutters

This is so true that at least one authority is opposed to even the automatic fire shutter, held open by centrifugal force. He claims that the action of the operator is to be encouraged to the extent of dispensing with automatic devices of this character, claiming that the operator should feel his responsibility. If a centrifugal release works properly, it will be faster in closing the fire shutter, than the best operator. But there is a certain amount of danger that it may stick. Of course this is not likely. If it is not in working order the trouble will reveal itself before the projection starts. If it is summed up it will refuse to open the shutter or will do it so sluggishly that the need of attention will be at once apparent. Besides the fire shutter there is the dowser. It would even be possible to make the dowser in a certain sense a part of the room, by having it geared or connected to the room-shutter system, so that the same release. which would let the shutters close might close it also.

But the law requires automatic closing devices. The point to be made is that the fusible link releases are really not good enough. There should be a release to be operated without waiting for the links to melt.

DOORS AND WINDOWS OF BOOTH

The windows in the front of the room are a matter of legislation. Pennsylvania decrees that there shall be two for each machine—one for the operator and one for the machine. The window for the machine shall not be more than six inches high and twelve inches long and shall be located and cut after the machine is in place. The operators' window shall be not more than four inches wide and more than twelve inches high. Among the requirements for the doors is that they shall be easily released by hand. The latter is a very sensible requirement. New York and New Jersey require automatic closing arrangements for closing the shutters, and windows of reasonable size are prescribed. Quite a volume could be filled with the results of the efforts of legislators of the different states to make motion picture projection safe. In the law of Pennsylvania the exact construction of the shutters is described. In other states it is left to the general sense of the constructor or state inspector.

There has to be an entrance door for the room. Accordingly Pennsylvania says that the door with six-foot by two-foot frame must have a spring to close it and a stop to preserve the hinges and to prevent it opening into the room. The main door does not seem to interest the legislators as much as the little window in the front wall of the room.

MATERIAL OF PROJECTION ROOM

The material of the room must be fireproof. The general tendency is to make it of asbestos board on an iron frame. This system is specified quite minutely in the laws. Angle iron for the uprights of specified size are prescribed, with T-irons in other places. Asbestos board is to be of specified strength according to the law of New Jersey, namely, to sustain a center load of at least 250 pounds on a sample twelve inches square. New York says the covering is to be at least one-quarter inch in thickness.

It will be found that while there is a good deal of similarity between the laws of different states, there are considerable variations.

SIZE OF PROJECTION ROOM

The size of the room is also a subject of legislation. New York says that it shall not be less than six feet in height, and that there must be not less than forty-eight square feet for the first machine and at least an additional twenty-four square feet for each additional machine. New Jersey requires them to be seven feet high and has the same requirements of area as those just mentioned for New York. Pennsylvania requires for one picture machine six feet by eight feet; for one picture machine and one stereopticon nine feet by eight feet; for two picture machines and one stereopticon twelve feet by eight feet. The height is to be at least seven feet.

Massachusetts for all such matters seems to rely on her inspectors.

VENTILATION OF PROJECTION ROOM

Ventilation is to be provided also. Pennsylvania prescribes a three by fifteen inch inlet for each of the four sides, these to be protected by wire nets, and a circular opening not less than ten inches in diameter near the centre of the top. From this a pipe of the same diameter must lead to the open air or to a fireproof flue. A twelve inch electric fan is to be installed in the vent-pipe. New York requires a current of air of not less than eighty cubic feet a minute to pass through the vent-flue, when the room is in use. New Jersey does not provide any special requirement for ventilation.

The laws being so varied and the work of construction being subject to state inspection the simplest plan would seem to be to have the erection of projection rooms done by experts. In this way trouble would be avoided, and there would be a certain surety supplied that the law was being complied with.

When the projection rooms in the larger theatres are studied it will be seen that they are very superior structures, in which nothing to ensure comfort of the operator and to protect the audience against panic has been omitted. These are quite large and the plant contained in some of them represents considerable capital.

The Projection Machine

The principle of construction of the modern projection machine is presented in the diagram. The parts are named on the diagram, so that it is largely self-explanatory.

Starting at the top there is the magazine or reel box. In this is placed the reel from which the film is to be unwound and displayed on the screen. The reel is carried on a pin or arbor, on which it is free to rotate with as little friction as possible. The great object to be sought for in projection of films is to effect the feeding with as little strain on the film as may be. The handle is turned by the operator, at about one turn a second. The operator and photographer are supposed to strive for this rate of turning the handles of their respective machines. The operator is allowed some license; it may seem better to accelerate or diminish the rate, according to circumstances and effect to be produced.

Course of the Film in the Projection Machine

From the reel, which is seen in the magazine, the film is drawn out and downwards by the sprocket roller, S; it is a little below and to the left of the magazine. On this sprocket, as on all the others, there are sixteen teeth, so that each full turn of a sprocket feeds four pictures, no more and no less. There are four perforations on each side of each picture. If the film is a little irregular four pictures are inevitably projected for each rotation of the sprocket.

The film is made to take the perforations by a pressure roller, V, which holds it in contact with the sprocket; a very light contact is all that is required as the teeth of the sprocket do the feeding.

The film forms a loop, L, and goes to the gate below it. The loop is quite an essential part of the arrangement. The introduction of the film into and through the machine preparatory to exhibiting it is done by the operator, and is called threading the machines. He has to take care to put it in with a loop both here and below.

The film next passes across the gate or aperture. Through the gate the light of the lamp passes, so as to effect the projection. The lamp, condensers, and objectives are indicated in the diagram and named in it.

The feed of the film out of the upper magazine is a constant feed, produced by four revolutions of the sprocket, s, per second. Its feed or motion across the aperture has to be intermittent. A picture is projected on the screen for a fraction of the sixteenth of a second. It is then cut off from the screen by a shutter intervening in the path of the light from the lamp, and during the period of obscuration the film is drawn or jerked downwards the distance represented by four perforations, which it will be seen is one-quarter the circumference of the sprocket. As soon as the shift is completed the shutter is turned away from the path of light and the new picture is projected. This intermittent feed is effected by the intermittent movement.

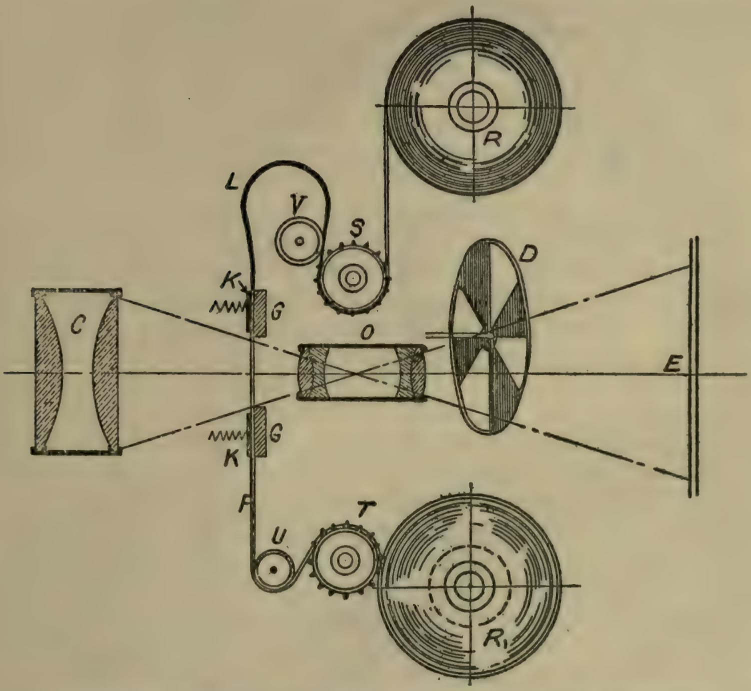


DIAGRAM OF PROJECTION MACHINE, LOWER LOOP OMITTED

THE INTERMITTENT MOVEMENT

At U is the intermittent movement, of the Maltese cross or Geneva type. This operates to give the sprocket a rapid quarter turn for each full revolution of the drive wheel into which the Maltese cross meshes.

Leaving the intermittent sprocket, the film is given another loop and then reaches the lower sprocket which turns with a uniform motion. It has its pressure roller, like the others. It then enters the lower magazine in which is a second reel, not free to turn, but geared to the rotating elements of the machine.

By following out the gearing as indicated in the diagram, it will be understood that all the sprockets revolve at precisely the same speed. Three of them have a uniform motion of rotation, while one has an intermittent motion, but it makes four turns per second.

The cut is purely a diagram; it is not correct as regards proportions and distribution of its machinery; the idea is to make as clear as possible the operation of the machinery of a projector, which in the actual machine is pretty well hidden owing to the necessity of adapting it to the smallness of the film pictures and to the focal lengths of the lenses.

THE TAKE-UP

The lower reel is turned by the operator with the rest of the machinery. It starts empty and to keep up with the sprocket feed must turn much faster at this time, than when it has been filled with film, and is of many times the initial diameter. An analogous problem is presented in other machinery, notably in the printing press. When nearly full the lower reel should not rotate but a fraction as fast as when it starts empty and of small diameter. The change of speed is done by a device differing in different makes of machines, called the take-up. The general idea is to turn the lower reel by a very gentle friction, as shown here a friction belt; in advanced machines friction wheels; in either case the friction is so slight that there is a varying amount of slip, which takes care of the increasing diameter.

INTERIOR OF THE MOTION PICTURE PROJECTOR

The interior of a typical modern moving picture projection machine is shown in the cut of the Proctor Automatic Motion

Picture Projector. A good idea of the gearing of the mechanism can be obtained from a study of the cut.

On the right is the lamphouse, which contains the arc lamp with inclined carbons. In front of the lamp is the condenser with its dowser, as the shutter for cutting off the light is somewhat inelegantly termed. In addition to the hand dowser there is one which shuts off the light automatically if the film breaks or runs off the reel as it is expended.

Motor Drive of a Projector

Above the centre of the supporting column is an electric motor which drives the machinery. This is the modern way of operating an important installation. When the projecting machinery is operated by the continuous turning of a handle by the operator, who has also to manipulate the carbons of the arc light, it seems as if too much is expected of him. In hand operated machines this is what he has to do for long hours right and left hands being occupied. It is impossible for hand rotation of the crank to secure even speed. But the electric motor turns the machine with perfect evenness. The speed of the drive may be regulated by a touch of the finger, to secure an instant change of speed. This is particularly useful when short titles, occupying but a limited length of film are to be projected. By this control the film can be made to move as slowly as fifty-five feet per minute, and can be fed at one hundred and twenty feet. The latter rate is double the regular speed, which is taken at sixty feet a minute. By this hand control the feed can be made to harmonize with the tempo of the music. At the present time the synchronizing of music and projection is considered a matter of importance.

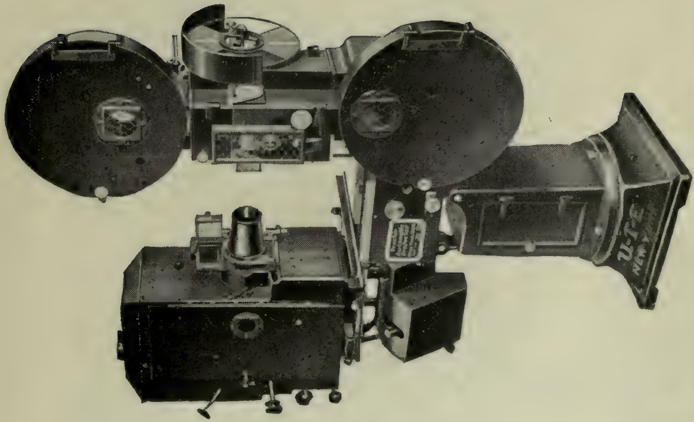
Besides the hand control, which is intended for sudden or temporary speed changes, there is a mechanical feed control. This gives a positive and uniform gradation in speed, uniform for any length of time, but changeable to other rates of feed as required. There are no chains or belts.

The Lamphouse and Head of the Projector

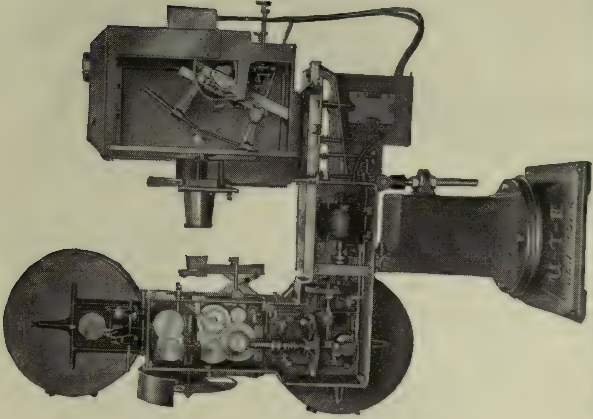
Next in order comes the front division as it may be termed. All projection machines may be thus divided. There is practically always a lamphouse. This is integral and by itself. In volume it is about one-half the machine. The other part is the feeding and projecting apparatus. Between the two parts there is usually a space clear of all machinery.

In the machine in the cut, this division is clear. The complicated gearing required to carry out the intermittent feed, taking the film from one reel in the upper magazine and after it has gone through the aperture and has been projected, rolling it up again on the lower reel, is contained in this part.

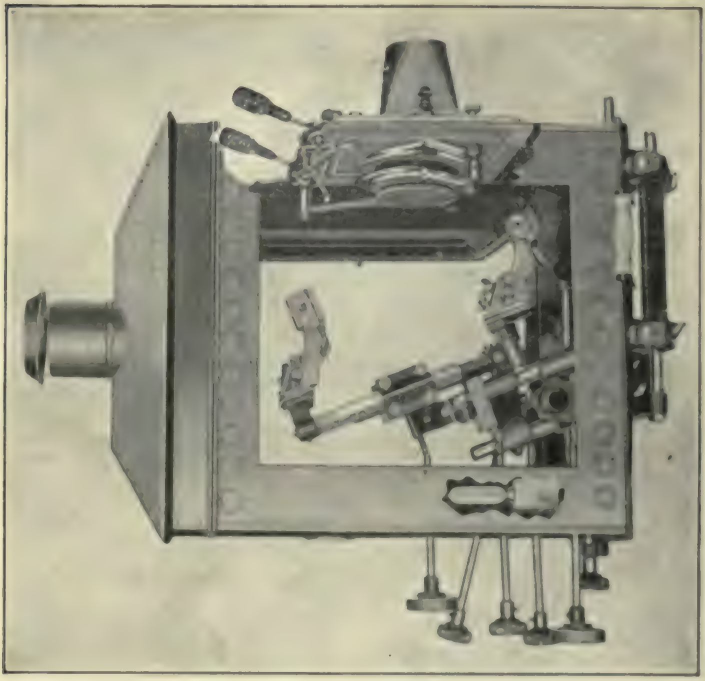
Here too is the objective lens, and directly in front of it the two or three bladed shutter rotates. The diagram shows what the machinery has to do. The illustration of the projector with cover plates removed, gives an idea of how the thing is done.



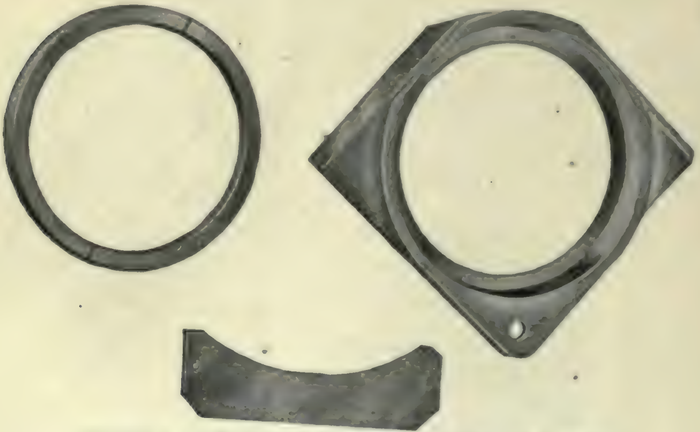
THE PROCTOR PROJECTION MACHINE



INTERIOR MECHANISM OF THE PROCTOR PROJECTION MACHINE



POWER'S TYPE "E" LAMPHOUSE AND LAMP SHOWING INSIDE DOWSER



POWER'S CONDENSER HOLDER, RING AND KEY

CHAPTER X.

The Two Divisions of the Projector

A PROJECTION machine may be regarded as made up of two parts; one is a rectangular box or case in which the lamp is placed; the other is the forward division which carries the two reels of film, the objective and the projecting machinery. If the whole machine is looked at, it will be seen that it resolves itself into two distinct parts, as described.

The Lamphouse

The lamphouse is made of sheet steel, and is a substantial structure. The illustration shows a typical one. The lamp is seen in place in it, ready to receive its carbons. From the rear of the lamphouse the various adjusting and feeding handles of the lamp extend. It is constructed to permit no light whatever to escape; when closed it must show not a single line of light through any opening.

Power Expended on Lamp

A lamp passing thirty or more amperes at fifty or more volts represents a surprising amount of electric power. Fifty times thirty are fifteen hundred, and this is the number of watts such a lamp absorbs. As there are seven hundred and forty-six watts to a horse power, it will be seen that a lamp may take over two-horse power of electric power in its operation. The primary object of the lamp is to convert this power into light. As the lamp operates the object practically is to convert this energy into heat, so intense that it will give a good return in light. It is not to be assumed that any proportion of it, that amounts to anything, is converted into light. It is far from easy to definitely state the amount of the power absorbed, which is converted into light. The equivalent of light with regard to heat is a rather uncertain factor.

Heat in the Lamphouse

If two-horse power of heat rate are put into the lamp, almost as much will be radiated from it or be imparted to the frame. The lamphouse is a source of much heat. As long as the lamp is working it is as if a stove or furnace were burning in it. Hence it must be built to stand a lot of heat. These are two reasons for its substantial construction.

It must not be small or contracted in size. It is an object to provide room for the lamp to be worked on for minor attentions while the lamp is in the lamphouse. It must not be necessary to remove the lamp for everything. Hence is is good practice to make the lamphouse roomy.

Two-Sided Construction of Lamphouse

A point in advanced construction of projection machine is to arrange them to be operated from either side as far as possible. The lamphouse is seen to have two doors on opposite sides. Peepholes with red glass set in them are provided to allow the carbon points and are to be inspected without dazzling the eyes.

Sometimes a ground glass reflector is arranged to give a sort of reflection of the carbon ends.

Such inspection is essential to adjust them properly.

Condenser Mount in Lamphouse

In the front is the opening for condensers. Here a frame is fastened in symmetry with the optical axis of the condensers, and to this a second frame is hinged, which carries the condensers.

Dust Produced by Arc Lamp

In operation a lamp produces considerable carbon dust and dust of ashes from the carbons. This dirties the condenser especially on its inner face. This requires frequent cleaning, once a day is a good rule. The hinged frame drops forward and down or swings to one side so as to expose the inside face of the condenser lens nearest the lamp for cleaning. It is not to be dropped down until it is cold or at least cool. The thick glass of such a lens gets very hot and retains its heat for a long time. It is not good practice to let them cool too suddenly as it may cause them to crack from sudden and irregular contraction.

Condenser Holders

Each of the two or three condenser lenses is held in a cast iron ring. This must not be too tight. The glass must have room to expand when the heat of the lamp affects it.

The condenser lenses in their iron frames drop into the hinged frame, which constitutes the mount. By giving the lens frame and the mount respectively a V-edge and a V-groove, each lens falls into position with the greatest accuracy.

A segmental "key" drops into the condenser mount to hold the lenses in place.

Adjustment of Condensers

The final adjustment of the condenser lenses is performed while the lamp is burning. This is requisite, because the lighted lamp gives the guide for the adjusting. The lenses are so mounted that this can be done. The rear one of the lenses, the one nearest the arc, can be adjusted from outside the lamphouse. The adjusting screw handle can be seen projecting from the condenser frame, immediately below the lenses.

Ventilation of Lamphouse

The ventilation of the lamphouse is provided by a chimney. It will inevitably get very hot.

The worst heat is due to striking the arc, as far as cracking, for when this is being accomplished at the beginning of operations the condenser is cold, and most liable to crack from the heat of the arc and carbon ends. Here the dowser comes into use. It is dropped in front of the lens and thus protects it from injury from sudden heating.

A light touch drops it. If the film ignites it can be instantly protected from the heat of the lamp by dropping the dowser, if for any reason the safety shutter does not operate. It is one more element of security.

Adjustment of Arc Lamp in Lamphouse

The principal or most frequent adjustments of the lighting system are done by shifting the carbons. Most of the shifting is done on the lower carbon. But in addition to these adjustments of the light for projection the entire lamphouse can be moved back and forward, and to right and left. The back and forward motion is generally given by rack and pinion or some equivalent mechanism. The lateral movement is in the Power projection machine for instance, done by hand, by direct pushing. It can be pushed well over to one side. On this side a special long focus objective is carried. When the lamphouse is shifted to this side the long focus objective, the "stereo" it is called by some in an abbreviation of the word stereopticon, comes into the optical axis of the condensers. A regular size lantern slide can now be put into the holder in front of the condenser and be projected on the screen stereopticon or magic lantern fashion.

The Stereopticon Lens and the Lamphouse

The focussing of the long focus objective must be attended to before the exhibition begins, so that when the slide is thrown upon the screen it will be projected in good definition at once. The stereo. lens is carried on a horizontal bar and is to be so adjusted that when the lamphouse is pushed over, the optical axis of projection lens and condensers will correspond and be one. The focus of the same lens, the stereo. must be such that the standard sized lantern slide mat will frame perfectly on the screen.

The diameter or width of the standard mat for lantern slides is three inches. If this figure is divided by 29/32, a factor will be obtained by which the focus of the motion objective must be multiplied to give the focus of the stereo. objective, which will frame on the screen in use. This factor is 3.31.

Thus if we have a four inch focus objective for the projection of moving pictures and it frames the picture well, the stereo. objective must be of 13.34 inches. This will then frame the lantern slide as far as width of picture is concerned.

It will be seen how accurate the construction of the machine must be to permit the large heavy lamphouse to be slid to and fro by hand and to come to an exact position at the end of the slide in each direction, so as to come into the optical axis of two separate objectives, over and over again without errors. The least inaccuracy would show in the framing.

The Dowser

Within the lamphouse and close to the rear condenser is a swinging shutter. When in its lowest position, this shutter comes between the arc of the lamp and the condenser, shutting off the light completely from the front of the lamphouse. This shutter swings, pendulum fashion. A handle extends upwards from it and by this handle it is swung up out of the path of the rays of light or is lowered so as to cut them off and stop the emission of light. This is the dowser.

It is of use in working on the active arc. The operator is freer to adjust the arc if the dowser is dropped, for then he can run it for the moment as hot as he wishes or can reduce it as suddenly, without fear of cracking the rear condenser.

The Dowser and Fire

The dowser, called a light cut-off in England is a metallic shutter, which is closed back of the condenser, between it and the lamp. matter of safety on account of the inflammability of the film. It is opened and closed by hand as occasion demands.

At the speed of projection machines any portion of the film This procedure is not only required to cut off the light from the screen as called for in the progress of the projection, but is a has only a small fraction of a second of exposure to the light. This is the time of its projection on the screen. If for any cause the motion of the film is arrested and a portion remains exposed to the heat from the lamp concentrated by the condenser it will ignite. The instant there is any apprehension of an ignition the dowser should be shut.

There is always a safety cut-off on all projection machines of standard American make, which works automatically, and it would seem that this might be enough. But this is kept open as long as the projector handle is turned. It operates by centrifugal force as it is described in this book. Therefore if anything was threatening to happen while the film was in motion the centrifugal apparatus would be inoperative, because the operation of the machinery would keep it open. But the dowser is always at hand and can be instantly shut in an emergency, without the motion of the machinery stopping. The combination of the hand-operated and automatic shut-offs is a double security, and conduces to safety in any emergency or special requirement.

Some dowsers take the form of a sliding gate or shutter, operated by a handle. The sliding shutter may be two-fold; such is shown in the cut. One section comes from the right, the other from the left, and the two meet in the middle as indicated by the double dotted lines.

Another form of dowser is of the rotating type. It works on an axle or shaft fixed parallel to the line of axis of the lens system. The shutter is a plate of metal and when swung down drops just back of the film. When the light is needed again, the plate is raised instantly by a handle projecting from the side of the objective or near it.

THE ARC LIGHT OF TO-DAY

The increased size of theatres has changed the state of things as regards the arc light. Formerly it was only small rooms, comparatively speaking, which were used for motion picture exhibitions. In former years it was the custom to use practically only two combinations of upper and lower carbons; for direct current the upper carbon was a 5/8 inch cored carbon, while the lower was a 1/2 inch solid one. This was to secure as well as might be a fixed position for the crater by means of the core in the upper carbon. This carbon was of course the upper one. It was thought a matter of indifference whether the lower carbon had any core for a D. C. current, so a solid one was used.

For A. C. work both carbons were cored, and were of the same size, 5/8 inch as both had the same work to do. At the present time the motion picture theatres are much larger and the lighting conditions for the projection machine are far more exacting.

CARBONS RECOMMENDED

Soft cored carbons are recommended; the following are combinations advised by the Nicholas Power Company.

For direct current up to 50 amperes for the upper carbon a 5/8 inch cored carbon, 12 inches long with a lower carbon 5/16 inch diameter and six inches long. The lower carbon is to be solid.

From 50 to 65 amperes an upper cored carbon 3/4 inch diameter and 12 inches long, and for lower carbon a solid one 11/16 inch by 6 inches long is recommended.

From 65 to 70 amperes a cored carbon 7/8 inch by 12 inches for the upper position and for the lower a solid carbon 3/8 inch by 6 inches is recommended.

Above this up to 100 amperes the upper cored carbon may be 1 inch by 12 inches, cored and the lower 7/16 inch by 6 solid.

All this is for direct current. For alternating current the following sizes are advised:

From 35 to 50 amperes cored upper and lower 5/8 inch diameter are recommended. For 45 to 65 amperes 3/4 inch upper and lower cored carbons, and for 65 to 80 amperes 7/8 inch cored upper and lower are specified.

The Alternating Current Arc Light

It must be remembered that the A. C. arc on its face is not the best light for projection. Much is claimed for one or the other make of A. C. carbon, that is carbons for use in lamps with A. C. current supply. But the fact remains that the production of a good crater is the most obvious solution of the arc light problem for projection, and the direct current gives a better crater than does the alternating current, at least under ordinary circumstances.

The alternating current light has one great advantage over the direct current one, and that is in the matter of reducing the amperage to the proper amount and keeping it regulated. In the use of alternating current this is done with a small loss of power by the choke coil. If we cut off the supply of gas to a burner by turning the cock a little, we reduce the consumption without expending power or using up gas in so doing. In the case of the alternating current the coil with its soft iron core acts to shut off the current without any but a trifling loss of power. But with the direct current lamp the resistance coil or rheostat wastes perhaps one-half the power of the circuit. It is as if we reduced the gas flowing through a burner by opening a second cock and letting some escape into the open air.

Thus each kind of current supply for an arc lamp has its good and bad points; if a choice is to be made between them it is probable that the weight of preference of operators and engineers would be awarded to the direct current. There is room for invention in getting rid of the regulation by the rheostat.

Resistance of the Carbons of the Arc Light

The resistance of the carbons is considerable and power is expended wastefully in overcoming it. To reduce this resistance carbons are often plated with copper or nickel. Copper is one of the best conductors of the electric current, and carbon is a poor one. The use of plated carbons in projection arc lights is far from universal.

A bad arc will give trouble from variations in illuminating power, and may hiss and sputter; cored copper plated carbons are supposed to avoid these troubles.

OPERATING THE ARC LIGHT

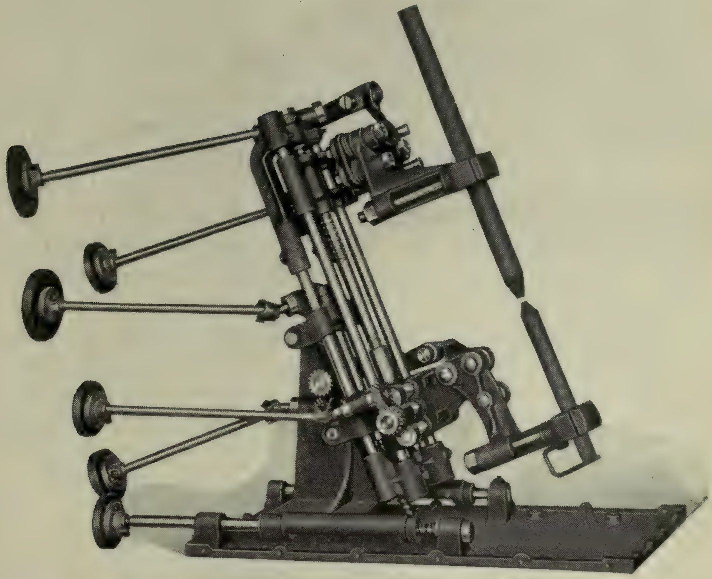
In using the arc light the operator will have to give it attention more or less of the time. A good electric feeding appliance will do most of the work for him, but the personal element is never completely eliminated. There are excellent feeding mechanisms on the market, but it will always be found that there is a hand attachment to enable the work of the machine to be supplemented by that of the operator.

THE POINTOLITE LAMP

The future may see the perfect light for the projection of views. It may be in the direction of the Pointolite lamp. In this a bead of tungsten is ignited to a high heat in a bulb, of the incandescent lamp pattern. It is an arc action, and the light is due to the heated bead instead of the heated crater. It is supposed to be completely self-regulating. Much experimenting has been done with it in this country, and something may yet come of it to benefit the projection engineer's great problem, the perfect light for his lantern.

CARBON HOLDERS

It has been pretty well settled that the best grip for a cylinder is a triangular aperture. This can be easily made to close upon the cylindrical object and hold it firmly. If the cylinder is to be held in a circular aperture, there is no way of closing it to fit smaller cylinders or of enlarging it to fit larger ones. Any change of this sort results in changing the shape of the opening from a true cylinder to a sort of approach to an ellipse. It is true that a square aperture can be arranged to change in size without ceasing to be a square, but the triangle is the simpler of the two. The usual way of holding carbons in a lamp, and carbons are cylinders, is by clamps, secured by screws and nuts. The nuts naturally are liable to get hot so as to occasion delay in changing carbons, irrespective of the necessary delay in screwing the clamps fast in place.



SIMPLEX TYPE "S" ARC LAMP

Quick Detachable Carbon Holders

To avoid this source of delay, for it is most desirable to be able to change carbons rapidly, a special form of carbon holder is being introduced, which does away with the screw clamps. The illustration shows the clamp in question. The carbon is held against a V-shaped metal block, quite irrespective of the size of the carbon as regards its diameter. There is an eccentric shaft, which turns and in doing so presses the carbon against the V-shaped block, the pressure or tension being given by a weight attached to the shaft. To release the carbon all that is necessary is to lift the weight, which operation set the carbon free so that it can be taken out. The new one is then put in place and the weight restored to its former position, when it clamps the carbon against the V-block.

In the ordinary practice the studs and screws are liable to break. If wing nuts are used they stick or are "frozen" at times; if hot it is far from a pleasant job to release and then to tighten them.

Lugs or Terminals of Arc Lamp Cables

The current for the lamp is carried to the carbons by an asbestos coated cable. To the ends of this, which enter the lamphouse, lugs or terminals are attached, of which several forms are shown in the cuts. The idea is to provide for a cable a terminal in the shape of a plate with a hole in it to go over and around the binding post or lamp terminal. The lug is made of sheet copper, part of whose length is bent into a sort of socket. The end of the wire of the cable, after the insulation has been stripped from it, is placed within the partly formed socket, and the metal is then closed around it, so that the wire is enclosed in a tube, with good electric contact. No solder can be used on account of the heat to which the cable end and terminal is subjected. A simple squeeze is relied on to give the electric contact and the mechanical contact. Screw bolts and nuts may be used, but the rule is to trust to the stiffness of the metal of the socket to retain the cable end firmly in place.

Connection of Cable and Carbon

Any loosening of the joint between cable and socket of the terminal would be a serious business, as it would not only introduce resistance, but would also tend to local heating with possibilities of serious trouble.

Cable-Clamps

In some of the lamps of the most recent advanced construction the use of lugs or terminals is avoided. The ends of the cables are stripped of their insulation and are clamped in jaws of peculiar contour, giving a sort of corrugated grip so as to retain the wires of the cable with much greater firmness than is possible with the lugs. Of these grips, as we may term them, several illustrations are given. It will be seen how firm they are in their hold on the wires and how there is no chance of the hold or grip loosening. After long use the conductivity of lugs is supposed to deteriorate, so they should be renewed from time to time. The same applies to the ends of the cables, where they lie in the clamps. The constant heat is supposed to take the "nature" out of them, and it is advisable to at least watch them, to remove them occasionally for inspection from the clamps. If they show indications of being brittle there should be no hesitation in cutting off an inch of the wire and stripping a new and fresh piece for introduction into the clamp. But the wire is not so apt to suffer this deterioration as is the thinner or more exposed flat ends of the lug terminals. If these become brittle there is special danger of their breaking off at the point where the socket and flat piece join. There is a liability to play at this place, and any vibration or motion involving bending of the flat metal piece is apt to weaken and eventually to break it.

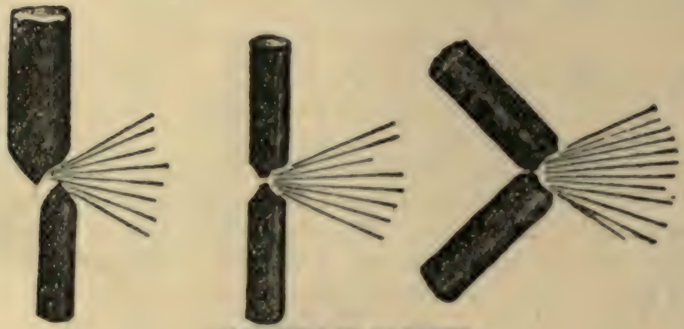
CARBON SAVERS AND ADAPTERS

To economize and save the short ends of carbons, appliances called adapters and carbon savers are supplied. These are a sort of socket, into which the carbon, too short to be received by the regular clamp can enter. Here it is held and the socket in turn is held in the clamp. By this contrivance a carbon can be burned down to the last inch or two. The saving effected is not very great but the idea is a good one and in the line of the old-fashioned "save-alls" of our grandparents days, when candles were in use. In the bottom of the socket of the candle stick there was a point about a half inch long, and when the candle had burned down to a small stump, it was raised in the socket and was impaled upon the point, so as to be nearly out of the socket. In this way our economical ancestors saved candle grease, and in an analogous way we may save carbon ends. The appliance is to be recommended as at least simple and sensible if not startling in its results.

POSITION OF CARBONS

The ordinary type of arc lamp, as constructed for projection purposes provides for holding the carbons at an angle with the vertical, and in a line with each other. There is a slight departure from complete alignment in order to bring about the facing of the crater on the positive carbon towards the screen. The carbons are fastened in heavy clamps and have a number of adjustments provided, for each of which adjustments there is a separate spindle with a handle at its outer end. On looking at the lamp the adjusting spindles will be seen projecting from it towards the rear of the lamp, and extending outside the lamphouse.

Each carbon can be moved back and forward by one of the handles. In the correct position the carbons are a little out of line, the upper positive carbon a little back of the lower negative one. Each carbon can also be moved to the right or to the left, and also up or down. The last movement enables the arc to be drawn out to a greater length or shortened as required, and by the same adjustment the arc may be moved up or down.



POSITIONS OF CARBONS

The carbons have one element of position, which cannot be altered. The line of inclination from the vertical is always the same. The axis of the one carbon if prolonged will either coincide with the axis of the other one or will be parallel to it and directly in front or back of it. In any other relation the carbons will be out of adjustment. If the axis of the one is to the right or left of the other, when prolonged, the adjustment is absolutely incorrect.

The carbons are held in clamps, the opening in which are of angular contour. The effect of this is that various sized carbons can be held in them. If they were of circular contour they would be adapted for only one size of carbon.

Position of Crater in Direct Current Lamps

The essential point in direct current lamps is to keep the crater on the upper carbon in the same place, in the axis of the optical system. This is opposite the center of the condensers. Accordingly the principal adjustments are made with the lower carbon. As it burns away the upper carbon has to be fed down a little at a time, the feed being almost exactly twice as fast as that of the lower one. All this applies to direct current feeding.

DETAILS OF ARC LAMP

The carbon clamps are carried at the end of brackets which are clamped in turn to the rack rods. These are made of heavy steel rods, square in section, and on each rod there is a rack cut, so that by gear wheels or by worm gear they may be moved up and down, carrying the carbons up and down in a true line with the greatest accuracy.

The weight of the bars seems disproportionate to the light work they have to do, for the carbons, which they carry have little weight, and could be supported by the lightest rods. But absolute firmness of motion is necessary. The mechanism is exposed to considerable heat as they are enclosed in the lamphouse with the arc. It is like being shut into a furnace.

ADJUSTMENT OF POSITION OF LAMPHOUSE

In addition to the adjustments of the lamp proper, the entire lamphouse can be moved, carrying with it the lamp, so that it is a lamp-adjustment. The lamphouse is carried on slide bars and can be moved back and forward in line with the optical axis, and a second movement is provided for directly across the back of the machine. In these movements it takes the lamp with it.

It will be seen that the most complete changes of position are provided for in these adjustments. The operator will become so familiar with them, that his hand will instinctively find the proper handle to be turned for each change of adjustment, which may be required.

The upper carbon is in direct current operation the one in which the crater is maintained. The crater is the source of far the greater part of the light that is used for projection of the pictures. It follows that the crater is the all important element of the lamp. As long as the upper carbon is in the vertical plane through the optical axis of the optical system, the first and controlling element of the lamp is in adjustment.

ADJUSTMENT OF LOWER CARBON

The upper carbon being in position as far as the plane of the optical axis is concerned there remains but one adjustment for it. This is the feeding it downward. It is consumed twice as fast as the lower carbon. Its feed has only one purpose, to keep the crater in the optical axis of the machine.

The lower carbon is adjusted to produce the crater on the part of the upper carbon, which directly faces the condenser. It has to be a little in advance of the upper carbon so that the arc will extend a little backward and thus bring the crater on the front of the upper carbon to a certain extent. The crater must also be in the center of the cylindrical surface of the upper carbon, or on the element of its cylindrical surface. which faces the condenser.

Accordingly adjusting screws operating on the rack bars are provided to move the carbons up or down, not both at once, but each one individually. There are screws and adjustments for moving the lower carbon to right or left, back or forward. The central point of all the adjustments is the crater. As in everything of the kind once the controlling factor is settled everything must be adjusted with reference to it. It follows that once the part of the upper carbon, on which the crater should form is in place the lower carbon must be moved about and so adjusted that the crater will be produced there. This place is at the lower end of the upper carbon, almost but not quite at its tip. The position of the lower carbon except from the point of view that it fixes the position of the crater is in a sense immaterial, so little is the amount of light, which it contributes to the projection of the pictures.

CORRECT AND INCORRECT POSITIONS OF CARBONS

The right and wrong positions of the two carbons are shown in the diagram, one which is quite familiar to readers of books on the subject of motion picture projection.

There is now another thing to be spoken of. The carbons in projection lamps are not always set in the alignment with each other as seen in the cuts and diagrams. Various other arrangements have been tried and are still in use. These other arrangements are shown also. They are not very common among motion picture lamps; they are principally to be met with in stereopticons. It is to be noted that the oblique disposition of the two carbons almost exactly in line with each other is dictated from the consideration of obtaining a crater with the direct current. But where the current is of the alternating type, there is no crater to be formed, as both carbons turn at the same rate and symmetrically. The same inclined position of carbons is used for the alternating current although it seems not to be the proper one. The inclination of the two carbons is for the specific purpose of producing a good crater.

As it is generally recognized that the best light for projection is one which will give a crater, which again is the direct current the standard projection lamp is made to do this thing. It follows that the standard lamp is made for direct current, and although it is used for alternating current is certainly not made for it as far as the original design is concerned.

Position of Carbons in Alternating Current Lamps

When used for alternating current the standard lamp as it may properly be called has its lower carbon shifted a little back so as to bring the ends of both carbons into the optical axis of the lens. This axis is a horizontal line. It seems perfectly clear that inclined carbons are not the proper arrangement to bring the ends upon the same horizontal line. One arrangement of the carbons is for them to be set at a rather acute angle, in a vertical plane and with the apex of the angle facing the condenser. The apex is not a point, but is two points in a general way. Each so called point is of some size however, and the fact that there are two of them, one above the other does not operate to give a theoretically correct light. A single area of incandescence as small as possible and facing the condenser is the ideal. This is what can only be given by the direct current. The desire to get this result led to the production of the high intensity arc light described elsewhere.

The point to be remembered is that if the alternating current is to be used the carbons should in theory at least be symmetrically placed with reference to the optical axis and with reference to each other.

CLAIMS MADE FOR SPECIAL A. C. CARBONS

The manufacturers of carbons claim that the alternating current problem has been solved by special carbons, made especially for the A. C. system. There is every reason to believe that improvements in carbons are being made from time to time, but it is hard to see how two points equally ignited can ever give a correct area of light for projection. The ideal lamp would be one of absolute symmetry, with a small ignited light giving area and one without any adjustments of the light producing elements. This result is given measurably by the gas-filled incandescent lamp bulbs with concentrated filament. The trouble is that the illumination is not as great as is needed for large sized screen work.

INCANDESCENT LAMPS IN PROJECTION

For these lamps a special lamphouse is made by some of the principal makers of motion picture projection machines. They have proved to be quite available for all moderate sized projections, and their area of ignition is probably no greater than is that of the arc lamp run on an A. C. circuit. It is also more symmetrical. There is nothing better for small sized projections, such as required in parlors or in smaller public halls.

VARIOUS SETTINGS OF CARBONS ON ARC LAMPS

It would seem that for alternating current lamps no position of the carbons would be as good as the vertical for both upper and lower carbons. Yet as the lamps for motion picture projection are made for direct current at least primarily, even when alternating current is used, the regular inclined position of the carbons is adhered to. The only change that is made is that the position of the lower carbon a little in front of the upper is changed and the carbons are set in a line with each other. Another change made consists in having the two carbons of equal diameter and identical in composition and in length.

The manufacturers of carbons naturally try their best to overcome the troubles incident to the alternating current arc. In it there is no possibility of concentrating the light in a crater. Worse than this is the fact that it has to be distributed evenly between the points of two carbons, each one being equally ignited, and emitting each of them, one half the light. The effect of this is that the ignited area is larger than is desirable for the work. The light should be as confined in area of ignited surface as is possible. A crater facing the condenser is the ideal as far as the arc light is concerned.

Arc Lamps in Stereopticons

For stereopticons we find that this idea is acted on and that a totally different position of the carbons is sometimes used than the one we have been observing as adopted for moving picture work. In the case referred to the carbons are placed at right angles to each other. The positive carbon is horizontal, its end facing and opposite to the center of the condenser. The negative carbon is perpendicular, and descends in position from the tip of the positive one. The feed of the positive carbon is horizontal, and forward towards the condenser; that of the negative carbon is upward. This goes to the production of a more or less perfect crater, if we may use such an expression. A crater will form. As long as its edge holds it may be taken as practically perfect; if the edge breaks and allows the flame of the arc to spread, its best feature will be lost.

For stereopticon work this is quite a favorite setting of the carbons. It is a little in the line of the Sperry search light lamp. The latter depends on the maintenance of an unbroken crater for its proper action. If the edge of the crater gives way the effect is greatly impaired. Cored carbons, those with a softer center than outside favor the maintenance of a good crater. The softer center burns away and the harder outside forms a wall or rim around the cavity thus left. The harder carbon burns more slowly for equal exposure. Thus the first action is for the core to burn and form a cavity or crater in the center of the positive carbon. As soon as this reaches a slight depth, the rim of harder carbon surrounding it protects it and it ceases to burn as rapidly as before. The crater attains its proper depth and holds it to the end if nothing happens in the way of the edge breaking down.

Rotary Motion of Positive Carbon

Another position of the carbons is that of a letter V, with its apex facing the center of the condenser. This would seem to be well adapted for alternating current lamps; it would bring the hottest and most luminous parts of both carbons to the front, so as to give the benefit of both carbons in equal measure to the projection. Where the alternating current is used it never seems right to have an unsymmetrical arrangement of carbons. Each one is doing the same work, and should be so placed as to share in the illumination equally with the other one.

In the high efficiency lamp described elsewhere a rotary motion is given to the horizontal positive carbon. It would be a simple matter to arrange a system of rotation of the horizontal positive carbon by hand, in the right angle disposition of the carbons just described. A slight or occasional turn might be very efficacious in keeping the crater wall intact.

It is here that the regular mechanical feed would be better than hand feed. The regular rotation of the high efficiency lamp would operate to keep the crater in one place. The intermittent and irregular rotation by hand would have a tendency to shift the crater a little at each turn and interfere to some extent with its position. This should be fixed and unchanging.

THE JABLOCHKOFF CANDLE

There is yet another possible arrangement of carbons. They may be placed in a horizontal position near to each other and nearly parallel. In this case their ends face the center of the condenser. It is like the old Jablochkoff candle placed in a horizontal position. The necessity with parallel carbons of providing some means of preventing the arc from running down the carbons was met by having an insulating composition between them.

The thing to be remembered in the arc light is that the principal light and the only light considered is that due to the heated carbon. The arc proper gives very little comparitively considered, and all attention must be concentrated on getting the fullest possible benefit out of the ends of the carbons. The arc localizes a region of very concentrated and very high resistance within a small space, and it is the heat thus produced and localized, which produces the illumination. We are dealing with an area of hot carbon, just as we might blow up the hot end of a match just blown out to cause it to become brighter. The arc, by its resistance to the electric current, heats the ends of the carbons, and it is their ignition that gives the light.

Arc Feed Controls

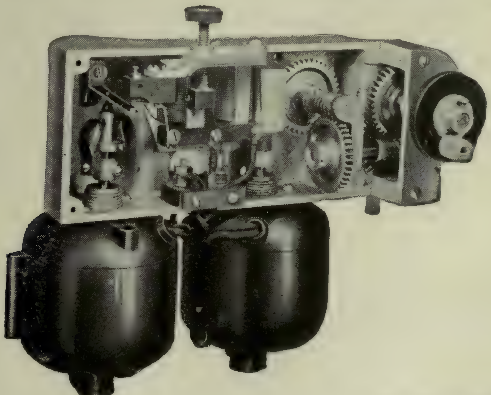
There are a number of electric arc feed controllers on the market. They are based on the fact that the length of an arc is what governs its resistance. A long arc has a higher resistance than a short one, with the same sized carbons. The object of the electric arc control is to keep the carbons an unvarying distance apart. There is an electric motor which feeds the carbons towards each other. The current; which actuates this motor is increased if the resistance of the arc increases, because the lamp is in parallel with the motor. If the arc becomes too long, its increase in resistance causes an increase in the current passing through the motor, and if the arc becomes too short, the consequent decrease in resistance causes the motor to receive less current and to make fewer revolutions.

This is the general principle on which the operation of a typical arc control depends. It is sometimes quite wrongly stated. The action of the motor is secured by connecting it across the arc lamp terminals, which brings it in parallel with the lamp.

The regular arc controls are not so simple as this description would make them. It gives the principle of parallel connection, generally utilized.

The Hallberg Arc Control

In the Hallberg feed arc control two motors are placed side by side, connected across the arc, as just described. One of the



HALLBERG'S ARC CONTROL SHOWING INTERIOR MECHANISM motors is called the feed motor. In the cut it is shown to the right. It drives a train of gears, which feed the carbons. The rate of feed is as nearly as possible that of the rate of consumption of the carbons. If not this it is a little less.

On the upper extension of the vertical shaft or axle of the

HALLBERG'S ARC CONTROL ON POWER'S LAMP HOUSE

left hand motor is a centrifugal governor. If the motor is increased in speed of rotation the governor presses up an electric contact piece, so as to make a contact. There is a resistance in circuit with the feeding motor. The closing of the contact by the centrifugal governor short circuits this resistance. This causes the feeding motor to speed up and to feed the carbons together faster. The left hand motor is called the governing motor. As it is in parallel with the arc the lengthening of the arc increases its speed, and this closes the contact above it, by the action of the centrifugal governor, and feeds the carbons together by increasing the speed of the other motor.

The voltage of the arc is kept within very close limits by this control. An even voltage is due to an even length, and this in its turn gives an unchanging intensity of light. The correct position of the arc and crater is also to a great extent secured.

In all electric arc controls some hand manipulation is to be expected.

CHAPTER XI.

HIGH INTENSITY ARC LAMP

THE High Intensity Arc Lamp of the General Electric Co. is based on the idea that the crater being the illuminating element of the D. C. arc, it is proper to place it in the proper position in the axis or line of projection of the apparatus, and to keep it accurately there. The lamp is constructed with mechanism to bring about this result, and the principle is a very obvious one, and secures the result with certainty, as the operation is mechanical.

Another result attained in the lamp in question is the production of a very small crater. In theory at least the crater should be a point; in the lamp we are describing it is about half the diameter of the crater given with the ordinary set carbons.

The carbons are of special composition especially as regards their cores. The positive and negative carbons have each its own formula of composition. They are of small diameter; eleven millimeters or forty-four one hundredths of an inch in diameter. This is virtually 7/16 inch. The lamp is designed to take a current of seventy-five amperes, and the carbons of the size mentioned are too small to take such a current for a length of any considerable number of inches.

FACTORS IN HIGH INTENSITY ARC LAMP

Three things are to be done; the crater is to be kept of small size; it is to be kept in the optical center of the projector; and only a small length of the carbon, the portion near its end is to carry the current. The current is to be conducted to the vicinity of the crater by the regular wire leads of the system.

The regular construction provides for an arc voltage of fifty-five volts, and an amperage of seventy-five amperes. If these figures are secured for its operation, it will require the minimum of attention from the operator. If they are departed from some little attention will be required on the part of the operator to maintain a correct feed of the carbons.

The lamp is a development of the regular inclined carbon D. C. projector lamp. There are two leading ideas carried out in its construction. One is to keep the crater at an absolutely fixed position, and this is brought about by what now seems the rather obvious plan of having the positive carbon horizontal in position, and at right angles to the plane of the condensers, and facing their center. This much being secured all that is necessary is to keep the crater in the center of the end of the positive carbon, and at an invariable distance from the condenser face.

This may seem elementary, but there are details to be carried into effect to secure the desired result. It will be seen that the problem was not so simple as it seems.

CARBONS IN HIGH INTENSITY ARC LAMP

The positive carbon is placed and held in a horizontal position and centered with the condenser. Below the positive carbon is the negative carbon. This is set at an angle of about 55 degrees from the horizontal. It projects downwards and towards the front of the machine.

The carbons are cored, the chemical composition of the core being different for the positive and for the negative carbons. The carbons are of the same diameter; they are eleven millimeters in diameter, about 0.44 inch or less than half an inch. They have to carry 75 amperes of current, and carbons of so small a diameter, if of any length could not advantageously act as conductors for so large an amperage. Accordingly the electric conductors are brought to the heads or ends of the positive and negative carbons respectively, so that but a very small length of each passes the current.

On examining the illustration of the lamp, the connection parts for the carbons will be seen at the ends of each; they can be recognized by the projecting filletts, four in number, which are required to cool them, they are so near the arc.

ROTATION OF POSITIVE CARBON IN HIGH INTENSITY ARC LAMP

The next feature is the most characteristic of all. The positive carbon has to have its crater kept in its axis or center. This is effected by rotating it along with its holder and carrier. The effect of this is that the crater is always in the center of the end of the carbon, and always directly opposite to and facing the center of the condenser.

The Carbon Feed

The positive carbon has to be fed forward also. This feed is intermittent. It measures a small fraction of an inch for each revolution of the carbon. The feed is obtained by the action of a feed screw working parallel to the carbon. A clamp grips the carbon, starting well back from its front. Through the clamp there is a threaded hole for the feed screw. The carbon is kept in constant rotation by a gear wheel at the rear of the carbon holder. The feed screw on the other hand is motionless except once for each revolution of the carbon. Then it receives a short turning motion, which feeds the carbon a little bit ahead.

The negative carbon has a similar feed screw, but it operates continuously. This carbon does not rotate. The carbon is gripped by a clamp with threaded hole for the feed screw, like the clamp of the other carbon.

Carboning the High Intensity Arc Lamp

To put carbons in the lamp both clamps are brought to their rearmost positions by turning the feed screws backwards. The negative carbon is then thrust through the negative carbon head obliquely downwards and through the carbon hole in the clamp. When in place about one inch should project beyond the flanged metal head. This carbon is nine inches long.

The positive carbon, which is eighteen inches long, to provide for its more rapid consumption, is pushed through the back of the carbon tube, through the hole in its clamp, and so on through the positive carbon head. It is pushed forward until it projects about 9/16 inch beyond the metal of the flanged positive head. Both clamps are tightened so as to firmly grip the two carbons. The wires of the circuit are connected to two wire clamps on the base of the machine, one for each carbon.

There are two safety clutches in the vicinity of the motor at the base of the machine, which operate to permit the motor to turn even though the positive and negative feed clamps have reached the extreme end of their range of travel. Otherwise the clamps being stopped from moving would stop the motor, and the armature would be in danger of burning out.

Resetting Carbons in High Intensity Arc Lamp

After a run of an hour and a quarter the clamps will have reached nearly the end of their travel, and will have to be reset. The positive carbon feed screw is turned so as to draw the positive carbon back until the clamp is at the end of its rearward travel. The negative carbon is then pulled upwards, until its lower end reaches the negative carbon clamp. It now protrudes several inches through the negative head. It can be thus manipulated because the positive carbon has been drawn back and out of the way. In all operations with the carbons this order must be observed; the negative carbon must be adjusted first, while the positive is a rearward position, so as to be out of the way of the negative one.

The positive carbon is now pushed forward until it projects the 9/16 inch as before, and if the negative projects too much or too little, it is pushed back or forward, until it projects an inch beyond the head as in the first setting.

The correct position and relations of the two carbons as they project from the heads is shown in the diagram. This brings out the cooling flanges clearly.

Starting the High Intensity Arc Lamp

To start the lamp the motor switch is closed and the motor starts into motion. The negative carbon feed handle is turned clockwise, so as to advance the carbon. The instant the carbons touch reverse the direction in which the screw was being turned, and this must be done instantly. Otherwise the motor will force the carbons together before the arc can form. This strikes the arc, and when the carbons are about 3/8 inch apart, the lamp will be operating regularly, and be ready for the projection work.

Rating of High Intensity Arc Lamp

The lamp is rated as regards the movement of the carbons at a current of 55 amperes and a voltage of 75 volts. If maintained at these figures it is supposed to burn with practically no attention from the operator, once it is lined up with the axis of the lantern and at the right distance from the condenser face. If the rating is not quite as prescribed. some little hand-feeding will be required.

In striking the arc it is evident that if the carbons were left in contact for even a few seconds the feed of the machinery would cause the two carbon ends to grind into each other to a certain extent and that a current of far too great amperage for the connections would pass, because the resistance of the lamp would be too little. This is the reason for the direction to separate the carbons instantly once they have been brought into contact.

Optical System and the High Intensity Arc Lamp

The adjustment of the lamp is explained fully in the directions which have been prepared for the use of operators. The general process is to get the center of the front end of the positive carbon exactly opposite the center of the condenser. This is done by raising or lowering the lamp as required by the lock-nuts, on four screw-bolts, which hold the lamp on its bearing-bars. In raising or lowering the lamp it is to be kept level, although a slight deviation from a level position will not do any harm. These nuts are hexagonal, and are put one above and one below a cross-piece attached to the base. Thus they perform the parts of adjusting nuts and of jam-nuts also, holding the lamp in position, so that it will not shift or change.

To move the lamp sidewise a screw is provided just below the base and not far from the center of the lamp, being a little forward of this point. This screw has a slotted head, and is to be turned in one or the other direction with a screw driver as required to move the lamp to right or to left. To enable this to be done the jam-nuts must be loosened, and the lamp will rest upon the lower nuts as it is traversed across the field by the lateral adjusting screw. When in correct position it is secured by turning down the upper jam-nuts.

At this point in the adjustment the positive carbon is in line with the center of the condenser, and is therefore in the axis of the lamp. When the lamp is lighted it may be and probably will be the case that the crater is too near or too far from the condenser. The arc will heat the crater to incandescence quickly, and the lamp should then project a light spot on the aperture plate. The whole lamphouse may be moved back and forth on its sliding rods until the spot is well defined and in focus at the plane of the aperture. But it may be that the condensers throw the spot a little out to one side. This trouble is overcome by shifting the lamphouse to one side or the other as may be required.

The diagram shows the correct position of the carbon ends, and gives the approximate distances to be given the ends of the carbons, one from the other. This diagram will bring out the position of the crater, and show how it will form in the center of the end of the positive carbon, being kept in the center by the rotation of the lower carbon so that any tendency of the carbon to travel to one side is absolutely corrected by its turning.

It is imperative that no oil or grease should be used on any part of the mechanism described. An arc lamp is a dust-producer, and it is stipulated as important that all carbon dust should be brushed or blown off the mechanism once a day. The lamp must be kept clean; it will suffer from neglect. The contacts should be inspected to see that they are not wearing excessively. There are springs on the contacts; if these become weakened they must be replaced.

ALIGNMENT OF HIGH INTENSITY ARC LAMP

To get the alignment of the lamp and to see that the positive carbon lies in the axis of the condensers, a perfectly straight pointed rod is recommended to be used. A metal rod is specified in the directions though any straight rod will answer the purpose. It should be a good fit for the carbon holder. It is to be pushed out from the rear so as to occupy the position of the positive carbon. Thirty inches is a good length. It is pushed forward until the front end reaches the plane of the aperture plate. The rod must be absolutely straight. The alignment of the rod is then tried with a pair of calipers. It should center with the opening in the aperture plate. It must be centered with the condenser opening, and this point is tested by calipering the rod from all sides of the circle of the condenser holder. The lamp is then adjusted to bring it into this position if the calipers show it to be out of true.

The front end of the lining rod, which is to be pointed, should come in the center of the aperture plate opening after the adjustment for centering it in the condenser opening has been completed. If this cannot be secured by the adjusting screws, in the manner described for the condenser adjustment, the moving of the lamphouse will effect it.

INCANDESCENT LAMPS FOR PROTECTION

Special incandescent lamps, with concentrated filament and running up to six hundred and nine hundred candle power rating are now used for projection, in places not too large for the amount of light such as these lamps project. The diagram illustrates the arrangement of an incandescent lamp equipment as supplied by the Power company.

The filament of the lamp, which lamp is made by one of the lamp manufacturing companies, is arranged in four parallel perpendicular spirals. This arrangement keeps the incandescing portion of the lamp in a small area; concentrated filament is supposed to describe such disposition of filament. With the outfit the Power's company supplies very full directions on the adjusting of all the parts so as to get the best results. It will be enough to say here that there are adjusting screws at the base of the incandescent burner to shift it backwards or forwards, up or down, as needed, and that there are set screws to fix it in position once the adjustment is found. Behind the lamp is a reflector as shown in the illustration on page 104.

It also shows the relation of the filament of the lamp and in this lantern an annularly corrugated condenser lens is used. It is placed with the smooth side next the lamp. In other Mazda lamp projectors the corrugated condenser is not used. The filament of these lamps is specially wound for the projectors and great care is requisite in getting proper placing of the lamp with reference to the reflected image of the closely coiled filament.

ADJUSTING THE REFLECTOR

In the adjusting the reflector it is so placed that it reflects the image of the four coils of the filament upon the aperture plate, so that they come between the images of the same coils as directly projected by the condenser. In this way the aperture plate will show two sets of images; one brighter than the other; the bright image will be that of the four coils of the filament as projected by the condenser directly upon the plate; the other will be that of the same coils projected between the others as reflected from the reflector and then focussed in diminished brightness. The plate will show, if the adjustment is correct, eight images of the four filaments, each second coil is the image from the reflection produced by the concave mirror.

IMAGE OF REFLECTED FILAMENTS

The point is most emphatically made that the reflected filaments must be brought by the reflector to a position on the plate image, directly between the image of the original filaments.

The corrugated lens is not always used; some manufacturers do not employ it for Mazda lamp projection.

THIRTY VOLT INCANDESCENT LAMPS

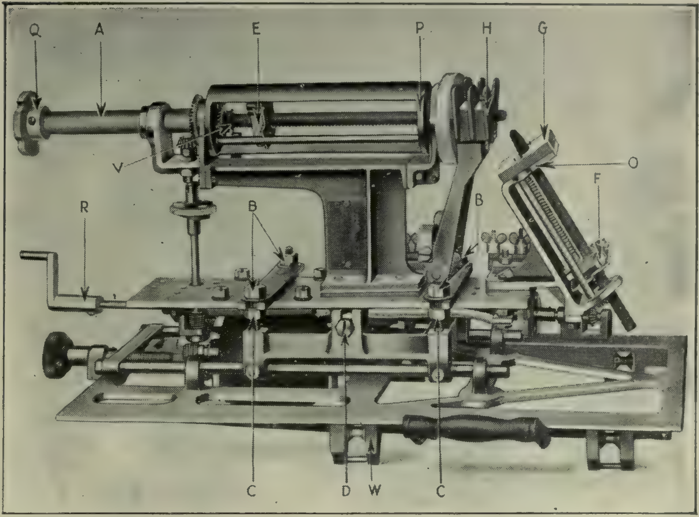
The lamps made for the projection machines of this type are of thirty volt potential difference only. The six hundred watt lamp should be operated at not over twenty amperes, and the nine hundred watt lamp at thirty amperes and no more. Any excess of current will shorten the life of the lamp. A lower amperage will diminish the light given. The ammeter should be watched during the projection of pictures to see that the proper amperage is being followed. It is easily adjusted by the rheostat.

BREAKING OF FILAMENT IN INCANDESCENT LAMPS

The operator must be prepared to have the lamp break down by parting its filament at any time. This is the principal disadvantage of the incandescent lamp. The replacing of a lamp, which has done this and gone out, is a matter of but a very short time if the lamp is not too hot to handle. The operator using incandescent lamp illuminants should have a pair of asbestos faced gloves; with these he can handle the lamp before it has cooled. Without them he may have to wait several minutes before replacing a burned out lamp. One thing to be kept in mind is to keep the lamp in a perpendicular position while burning; otherwise it will be apt to break its filament.

CHANGES IN RESISTANCE IN INCANDESCENT LAMPS

The incandescent lamp changes its resistance as it changes its temperature. When it is lighted its resistance, as it has not had time to get hot, is less than it will be after a few seconds of ignition. The principle of all projection is to make the lamp do its work as well as possible, and in the case of an incandescent lamp to give the maximum of light without injuring the lamp by passing too great a current through it. It is true that the lamp will last longer if operated at a low voltage, but it will give an inferior light



GENERAL ELECTRIC COMPANY'S HIGH INTENSITY ARC LAMP

if this is done. If the voltage is increased, the lamp will burn out and be spoiled sooner than is to be expected. It will be understood that what wears or burns a lamp out is too much current, and the current in a lamp varies directly with the voltage. But what is prescribed by the makers of incandescent lamps is the amperage, and the operator is supposed to watch his amperemeter or ammeter, as it is usually called. But recollect that the correct amperage is given for the lamp when hot, so do not take a final reading the instant the lamp is turned on but watch the ammeter for a few seconds, so as to adjust the rheostat as the lamp getting hot increases in resistance and takes less current than at first.

Simplex Incandescent Lamp Appliances

The Simplex incandescent lamp appliance uses the regular type of condenser. What has been described about the adjustment of the other lamp applies in general to any incandescent lamp apparatus. The Simplex company recommend adjusting the direct and reflected film images on a wing of the shutter. The condenser lens projects them on this if the lamp is brought a little nearer the condenser than in the final projection position. This is because the shutter is farther from the condenser than is the picture on the film, so to get the images in focus on the shutter blade the lamp filament has to be nearer the condenser, which is the projecting lens in this case, than when the focussing of the filaments is desired to be in the plane of the film. Here is where it should be for projection of the pictures on the screen. Accordingly a good system is to adjust the incandescent lamp and the mirror using a shutter blade for the reception of the images of the film. Then when the adjustment is perfect a card is held in the gate or the fire shutter is used for the purpose, and the projection of the filament is transferred to this plane or position so as to be in focus there and the projection is proceeded with as soon as required. The last slight adjustment is merely in the way of focussing the objective. The projection of the filament is transferred to the plane of the aperture plate or film position by sliding the lamp house back. This transfers the focus of the filament image nearer to the condenser.

If the shutter blade is to be used as the surface on which to project the filament image for adjusting the lamp and reflector, the front lens, the objective, is taken out of its tube so as to let the light from the condenser have a clear path to the shutter blade. It is replaced as soon as the work is done.

Stereopticon Model Incandescent Lamps

Incandescent lamps are made on the stereopticon model, as it is termed, for other voltages than thirty volts. They can be procured for one hundred and ten volts pressure, or various other potentials. The filament is not always arranged in coils or helices as shown in the cuts. It is always concentrated. The lamp should never be inclined at an angle exceeding forty-five degrees; it is better practice to keep it practically perpendicular. If it is placed in an approximately horizontal position the film will probably break, perhaps almost at once.

CHAPTER XII.

THE MAGAZINE

THE reel carrying the film and ready for projection is inserted into the upper magazine. Out of this it is fed by the intermittent motion and take-up down through the gate or aperture to the lower magazine. Here it is rolled up on another reel. When the reel is exhausted the reel is taken out of the lower magazine for rewinding.

As there are several sizes of reels the magazine must be large enough to receive the large sized ones.

The magazine is a case of steel. It may be square in shape or round. The large sized reel being fourteen inches in diameter gives the base for determining the size of the magazine. In the center of the upper magazine there is a spindle. On this the full reel is slipped and is free to turn on it as film is taken from the reel and fed through the gate.

The lower magazine has a central spindle also. This spindle is geared in with the take-up motion, so that the film as it is drawn out of the upper magazine and fed through the gate will be reeled up on the reel in the lower magazine. This operation must be neither too fast nor too slow. It must not affect in any way the intermittent motion.

The same applies to the delivery of film from the upper magazine. The film must come down to the intermittent motion sprocket perfectly free and without any strain. The film is drawn out of the upper magazine by a continuous motion sprocket. The film therefore is strained tight between the reel and this sprocket. The next sprocket which operates on the film to draw it across the gate is the intermittent sprocket. So that the film shall come to this sprocket perfectly free and unstrained a loop or slack part is left in the film between the two sprockets. Thus the first one draws the film out of the upper magazine continuously and feeds it directly to the loop.

Before the film enters the lower magazine it forms and must maintain a lower loop. If the film is patched or torn, and if there is too much tension on the frictional take-up, the loop may disappear. In such case it is said to be lost. If it is lost the matter must at once be attended to. It is essential that the feed into the lower magazine shall not affect the intermittent feed.

The film after it is drawn out of the upper magazine has a loop or slack place in it; before it enters the lower magazine it must also have a loop.

The Fire Trap of the Magazine

The film as it enters and leaves the upper and lower magazines respectively passes through a small opening in the periphery of the magazine in question. This is the only opening into the magazine, once the door is shut. Each opening is provided with two rollers. These almost close it. The film passes between them. As the film is very thin the opening between the rollers is very small; the rollers are so close together that when the film is in place the space between them is completely filled.

This opening with the rollers nearly filling it and adapted to make an almost tight joint when the film is in the space between the rollers is called the fire trap. If the film catches fire, and the fire reaches the film at the fire trap, the latter is supposed to exclude it from the magazine. Often the fire, if a film does catch, will not pass beyond the gate. The metal work at the gate on front and back of the film protects it in great measure from burning outside the limits of the gate. Often when it does ignite a little square hole the size of the gate and destroying only a single picture is the result. But if the fire runs down or up the film and gets into the magazine a disagreeable fire results. No harm can come to any person in the audience or about the projection room. Everything is fireproof. A quantity of smoke may be produced, and the audience may be frightened. Injury to the machine will infallibly be the consequence.

The object of the fire-trap is to prevent such an occurrence, and the possible panic of the spectators.

The magazine is sometimes of square shape, and sometimes of circular outline. Sometimes there are windows or a window to admit of seeing the reel as it is in place. The operator can then see if it is approaching the end.

THE REEL

The film reel has received considerable thought. Originally they were a very simple affair, but they are made more substantially now than formerly, and some minor improvements have been introduced as well as some important variations in construction and even in principle of operation.

They consist of a hub with flanges. The latter are of various diameters according to the length of film the reel is to hold. The standard length of film for a reel is one thousand feet. This is taken care of on a reel of ten inches diameter. This is a standard size.

The hub or central drum, on which the film winds, the diameter increasing as it accumulates until its layers fill the reel practically to the extreme diameter of the side flanges, is sometimes made of wood. This puts a little more combustible material into the magazine, and the practice is not to be commended. It may be made of metal and the reels embodying this feature are to be preferred.

SIZES OF REELS

Other diameters of reels are eleven, fourteen, and fifteen inches. The larger sizes take two thousand feet of film.

The sides or flanges of reels are made of sheet steel stampings or of heavy steel wire.

As the film comes off the reel it passes through the fire trap and goes through the machine. Care must be taken to have the film side next to the lamp, and the pictures must be upside down.

On the hub of the reel there is a catch of one kind or another, which catches the end of the film, so that the film will be held for winding on the lower film or for rewinding as the case may be.

Some complaint is made of the hub arrangements wearing out rapidly. New clips and keyways are to be had to replace old and worn ones.

NON-REWINDING REELS

One of the regular operations of reel manipulation is the rewinding. This is not without value as a means of detecting bad spots in the film. The rewinding is done rapidly compared with the feed in the projection machine, but the film as it is being rewound can be passed through the fingers and weak or rough spots and incipient breaks can be thus detected.

A number of reels have been invented to get rid of the need of rewinding. The idea embodied in them is to start the winding on the outside. Thus a spider may be imagined so constructed as to get smaller in radius as the film is wound on it. Then the new layers of film would have to slip in between the collapsing spider on their inside surface and the preceding layer of film on the outer surface. A number of these have been patented and they are constantly appearing in the patents granted.

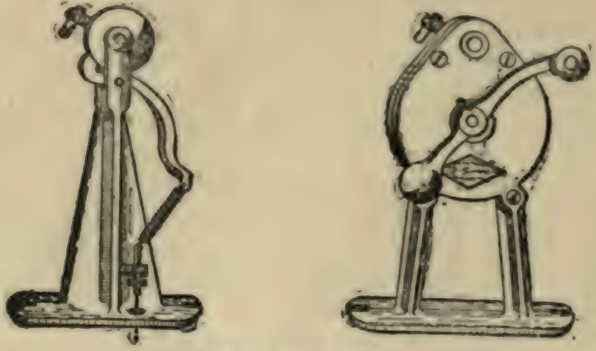
But rewinding is not a long operation and it not only gives a chance for a quick inspection of the condition of the film but can be supplemented by the addition of a cleaning appliance. Through this the film is drawn as it is rewound. It is shown elsewhere in this book.

The Simplex-Boylan Reel

The Simplex-Boylan reel is quite an innovation. The standard rotation of the lower reel is effected by a frictional take-up fully described elsewhere. This reel has a frictional drive in its construction, which will do the work of the regular take-up. The latter may be set as tight as possible, but the reel we speak of will do the take-up without it.

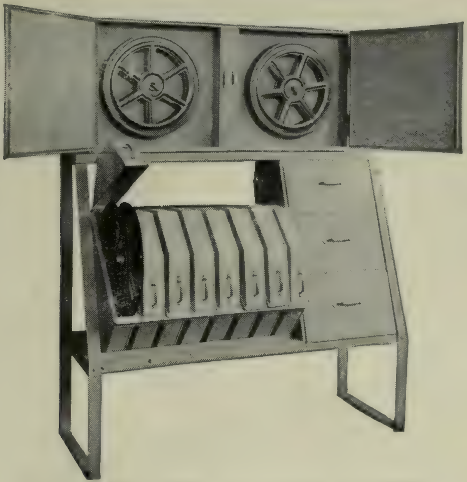
Rewinding the Film

After a reel has been exhausted of film, the film, which was on it when it was put into the upper reel box, is transferred to the lower reel. But the film now on the lower reel is wound in the



FILM REWINDER

wrong direction. The beginning of the film is next the center of the reel, and the part on the outer layers of the coil of film is the end of it. If the reel were now used to give the film a projection on the screen, the subjects would come out backwards. In the usual practice the lower reel is placed in a stand and the film is wound off from it upon another reel. On this second reel the film comes in proper direction, and the first pictures of the play are brought to the outside of the newly wound reel. This process is rewinding, and while it does not seem to be a serious matter, it is considered one of the operations it would be an advantage to dispense with.



FILM REWINDER AND REEL CABINET

Rewinding Machines

Rewinding machines to be operated by hand are shown in the cuts. Two standards are mounted on a base, and the standards are provided with short shafts at their tops to carry two reels. The reel on which the reversed film is to be wound is mounted on the left-hand standard, on which it is free to turn. The reel, which is to be wound with the film, is carried by the other standard. The shaft on this, the right-hand standard, is turned by hand, through multiplying gear, by means of a handle as shown in the cut. The multiplying gear enables the film to be rewound very rapidly. The effect of the rewinding is to bring the film with its forward end outside, so that it is ready again for the projecting of its pictures. The whole object of rewinding is to put the film, with its first pictures on the outside of the roll on the reel.

Multiple Width Films

Suppose that a film was wide enough to take two rows of pictures, side by side. One set would be in the regular order; the other set, parallel to the first set would be in reverse order. The reel carrying the film would be put into the case and threaded as usual, and the pictures on the first set would be shown. As the bottom of the film would be reached, an automatic shift would carry the film across so as to bring the second reverse row of pictures into line. This set would be wound back upon the upper reel, and as they were reversed, they would appear in proper order and motion on the screen. When this set was exhausted, the film would be wound on the upper reel, already for another exhibition. There would be no rewinding.

The use of parallel reversed sets on the one film is not a new suggestion; on a small family machine three parallel sets have been used on a film, with automatic shift.

The Sprockets and Idlers

The film on which the photographs are contained, which are to be projected, is governed in its motion and in its timing by sprocket rollers. These are rollers of steel, of the most accurate construction, a little wider than the film, and having teeth around the circumference at each end. The film has a series of perforations at each side, the two rows being spaced as far apart as are the two rows of sprocket teeth on the roller.

The Perforations of the Film

There are miles of film produced daily. Along every foot of the film there is a series of these perforations, made with mathematical exactness. Whether the film is made in Rochester or elsewhere, it is of standard width. This enables it to fit the fire trap and gate and other parts of any projection machine in the country. But this is not enough. The perforations must be such as to fit the sprocket wheels or rollers of all motion picture machines.

The film therefore has to be standardized from two standpoints, it must be of the standard width and it must have the standard perforations to fit the sprocket roller teeth.

The whole operation of a projection mechanism depends upon the holes perforated in the edges of a piece of thin celluloid film. It is one of the most striking instances of standardizing to be found.

There are four perforations to each picture. This means that there are four teeth on a sprocket for each picture on the film. The circumference of the sprocket roller is such as to contain sixteen teeth, enough for four pictures.

RELATION OF FILM PERFORATIONS TO SPROCKETS AND PICTURES

Such is the regular practise; it is based on the intermittent movement. This acts upon the roller, which effects the intermittent feed, four times in each revolution of it or once for each picture. The shaft of the intermittent feed device, turns once for four revolutions of the wheel actuating it. Thus it will be seen that the motion resolves itself into a fourfold division, so that the sixteen teeth on the sprocket side, corresponding to four pictures harmonize with the intermittent movement, which also is fourfold in action.

This division into fours is not necessary. In this book is shown a three-armed intermittent movement and there is a five-armed one. Such can be very simply reduced by gearing to operate a regular sixteen-tooth sprocket. So long as the feed sprocket is given its four impulses per revolution, four pictures will be projected per revolution. This is practically universal. The rest is a matter of gearing.

The miles and miles of film, which are produced are perforated with the greatest attainable accuracy. If the perforations are irregularly placed, flickering will ensue. The presence of flicker indicates bad perforation. This at least is one of the prominent causes, for there are others.

THE FILM AND THE IDLER

As the firm is fed by the intermittent motion of the intermittent sprocket, it must be held so that each tooth of the sprocket will pass through a perforation of the film. To ensure this the film must be held against the roller by an idler. This is a smaller roller carried by a swinging frame, which roller is pressed by a spring, bearing against the frame, so as to hold the film in contact with the sprocket roller. This idler presses the marginal portions of the film against the surface of the roller, next to and close to the teeth. In this way it is made certain that the sprocket teeth go through the perforations in the edges of the film. The surface of the roller, from which the teeth project, is made of the exact diameter to give a circumference equal to the length of film containing sixteen holes.

The sprocket rollers are essentially an accurate feature of the machine.

The Perforations and Flicker

If the perforations in a film get worn, so as to be of irregular size, it has the same effect as if they were irregularly spaced. They will average out with perfect correctness, but the individual irregularities will make themselves felt in the projection by a flicker. The film may have been originally perfect as far as the perforations are concerned, but long service may cause the film to run irregularly, if the perforations are worn by use.

Action of the Different Sprockets

Of the three sprockets the first one directly under the upper magazine, draws the film at a constant speed through the fire trap out of the upper magazine. Thence it passes to the gate and is drawn down through the gate and across the aperture by successive intermittent movements, produced by the intermittent sprocket directly below the gate. The film is then fed by the lower steady feed sprocket to a point over the lower magazine. The turning of the main driving shaft of the machine turns the reel inside the lower magazine, so that the film as received from the lower sprocket is pulled through the fire trap on the lower magazine and is rolled up on the reel inside it.

Such are the actions of the three sprockets. Each is of accurate diameter, and has its own idler to keep the film against it with the sprocket teeth passing through the perforations.

The Loops in the Film

To ensure accurate operation of the sprockets, or rather to ensure independent action of each one, two loops are formed in the course of the film. One is between the upper sprocket and the gate; the other is between the intermittent and the lower sprockets. It is quite essential that these loops are always preserved in place.

Aligning the Sprockets

The course of the film is determined by the sprockets. It is obvious that if there were only two sprockets the film would always be in alignment as far as they are concerned. But as there are three sprockets and an aperture plate, and as the film must be in alignment with all of them it is not as simple a matter to secure alignment. The test for alignment is made with a short piece of film. Use as new a piece as you can get at. Worn film will not answer for the test.

Pulling back the idler put the film on the intermediate sprocket, and close the idler upon the film, so as to hold it against the edge of the sprocket. Take the end of the film upward across the face of the aperture having the gate open. Then catch the film on the upper sprocket, just as was done for the intermediate one, and stretch the film by turning the flywheel backward. The teeth of the sprockets in this test must be in the center of the holes in the films, considering them sidewise. When this has been done, if the alignment is perfect, the film will have its edge in accurate line with the tracks on the aperture plate. The aperture will be in a position central with the picture on the film. This is the test of the alignment with the aperture plate.

Now examine the way the film rests on the two sprockets. If it bears evenly on both edges of both sprockets, and it is out of place on the aperture plate the indication is that the aperture plate is out of true. In some machines the thing to do is to drive the top to one or the other side by a light blow. In such cases a block of wood should be used as a sort of punch or drift pin. It should be placed endwise with one end against the part to be acted on and the other end may be safely tapped with a hammer. On no account drive directly on the metal with the hammer, unless the latter is a copper or rawhide hammer.

In the Power machine the aperture plate is secured to the machine by four screws, which pass through slots in the aperture plate. This makes it possible to adjust the plate sideways by jarring it. If it does not yield to light jarring, the screws may be loosened and the plate can then be moved to one or the other side with the fingers, and when it is in place the four screws must be set up again so as to secure it.

MINIATURE ADJUSTING LAMP IN PROJECTOR

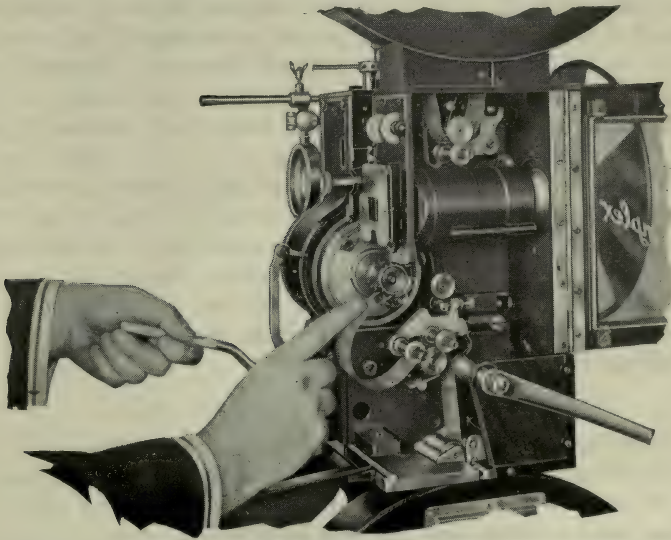
Again referring to the Power machine there will be found in it a miniature incandescent lamp a little distance from the aperture plate and down below the level of the axis of projection. When this is lighted it enables the operator to look through the film as it is held in the gate, to see if it is in alignment in all ways. This observation will tell him whether the film is in alignment with the sides and top of the aperture. If out of line and to one side or the other, this will be at once seen by looking through as the little lamp reveals the picture. It may be that the picture is correctly placed as regards lateral position, but the vertical placing has to be looked to. In threading the film, the little lamp plays its part. The operator looking through the film gets it as nearly right in the vertical position as possible. He shifts it on the sprocket roller of the intermittent movement, so as to have it center in the vertical direction. But it is evident that it may and indeed generally will be impossible to get the picture exactly right by shifting it on the intermittent sprocket. There are sixteen teeth on the sprocket. In adjusting it the film is lifted over the teeth. The smallest adjustment, which can be effected thus is one-sixteenth of the circumference of the sprocket, and this is one tooth, and there are four teeth to each picture. Shifting it a single tooth will adjust the picture one-fourth of its height. This is manifestly not close enough.

THE FRAMING CARRIAGE

The intermittent movement is carried on a framework, termed the framing carriage. This is a substantial piece of mechanism; the intermittent movement has to be held securely in position and to be free from any shake whatever. The framing carriage supports it in this manner, and is arranged to shift the film up and down in a vertical direction, shifting the intermittent movement with it. This motion is imparted to it by hand. A lever projects from the head of the machine, as the mechanism carrying the objective, gate and related parts is called, and by moving this lever or handle the intermittent sprocket, with the film held in place on it by the teeth of the sprocket and the idler, is moved up or down as required. The movement is absolutely vertical. There is no disturbance of the relation of frame and picture, except the vertical displacement of the picture.

Framing the Picture

In threading the film the handle of the framing carriage is set half-way up and down, in a central position. The film is threaded.



SIMPLEX FRAMING DEVICE--FRAMING IS ACCOMPLISHED BY REVOLVING THE INTERMITTENT SPROCKET ON ITS OWN AXIS

The operator looks through the aperture, with the little lamp burning, and shifts the film over the teeth of the intermittent sprocket until it is nearly correct in position. It will generally be a little out of place. Its correct location as retards the vertical position can be given to the minutest fraction by the handle of the framing carriage. To secure absolute accuracy the picture may be projected, if there is a chance, and the magnified image on the screen will enable the vertical adjustment to be given with perfect accuracy.

The adjustment by moving the framing carriage up and down is a very accurate one. It is quite possible to do it while the audience is present, if the picture is not too badly out of position. It does not take more than a second of time, and the utmost that it can be required to do is to move the picture one-fourth of its height.

The Intermittent Movement

The action of the intermittent movement is now pretty well standardized. Standardization is not always an unmixed blessing but certain things in projection have become definitely standardized, and it is fair to say, greatly to the advantage of the work.

Each foot of film carries its sixteen successive pictures, and this foot of film is supposed to go through the instrument in one second. The sprocket in one rotation feeds four successive pictures, so that four revolutions of the sprocket take place in each second, if at correct speed. The speed of course varies somewhat.

The intermittent movement has to move the film through the length of four pictures, by four intermittent feeds for each turn of the sprocket. The intermittent movement imparts this series of movements to the sprocket, each motion of ninety degrees angular measurement, and between these movements, it has to be held rigidly still.

The Period of Projection a Rest Period

It is during this period of rest that the picture is projected. It will be evident that the intermittent movement has an important work to do. In each quarter of a second it has to turn the sprocket once around, and this not by a simple rotation, but by four separate motions, each turning it one-quarter of a revolution.

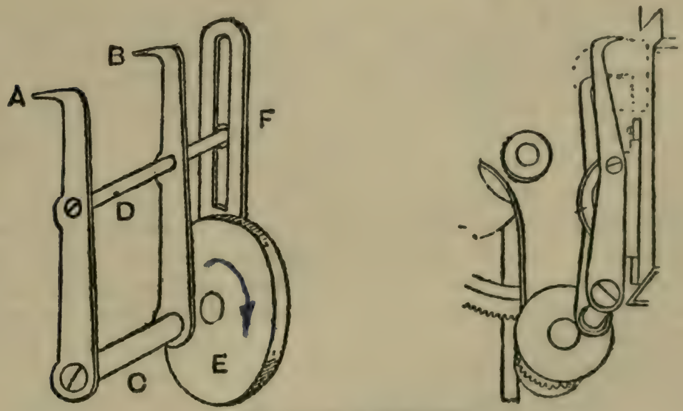
In each second there are sixteen of these ninety degree feeds as we may term them, and between the feeds there are sixteen periods of rest. This must all be done with mathematical accuracy, and without noise, and the film must be fed not by jerks, but with smoothness or it will be torn or otherwise injured.

THE ESCAPEMENT

The intermittent movement is sometimes called the escapement. An early form is the claw movement, which is still in use, although it is pretty well superseded by the Geneva and other devices. The diagram of its construction is given here.

THE CLAW MOVEMENT

The wheel, E, rotates at constant speed. Near its outer edge of periphery is a pin, and this pin holds the lower ends of the double hooks or claws, A, B. These claws are set at exactly the right distance apart to accurately correspond with the width of the film between the perforations, so that they will fit the perforations, one hook on one side and the other on the other side of the film. Thus they catch two opposite perforations.



THE CLAW MOVEMENT

Another pin crosses the central portion of the shanks of the hooks, as shown. This acts as an axis on which the claws can oscillate. As the wheel, E, turns it moves the claws up and down, constituting a crank. The central pin is retained by the slot in the bracket, F; this permits it to move up and down and the crank action of the wheel, E, and pin near its edge, as the wheel turns in the direction indicated by the arrow, pushes the claws upwards and in against the plane of the film, so that they enter two opposite perforations. This they do at the uppermost part of their stroke. As the wheel continues its rotation it draws the hooks down and as it completes the down stroke, and starts to raise the hooks again, the motion withdraws them from the perforations.

The motion of the claws is a combination of an up and down movement and of a forward and backward one, the one producing the requisite intermittent feed of the film, and the other hooking and releasing the claws alternately, once for each picture.

LUMIÉRE AND THE CLAW MOVEMENT

The fact that the claw intermittent movement was used by Lumiére in his machines shows that it is no makeshift. There is one very valuable feature about its practical operation. It acts directly on the perforations at the side of the film in the close vicinity of the picture being projected. Film has a way of shrinking and changing in length. This affects the accuracy of registration and is in the direction of causing flickering, if the part of the film distant from the gate is acted on to produce the intermittent feed. Suppose the pull to draw the picture into the gate was exercised on a part of the film three or four inches distant from the picture, any shrinkage of the film might very well make itself visible on the screen under such circumstances. The shrinkage of the three or four inches although very slight in amount, would be many times magnified on the screen. An irregular changing of length would cause flickering; a regularly distributed change might only exact readjustment of the gate or framing of the picture.

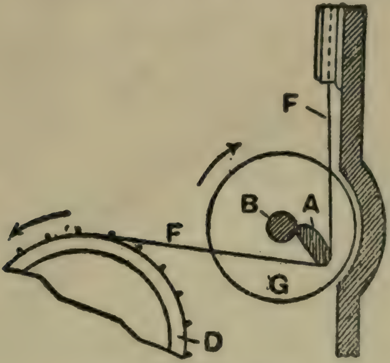
THE DOG MOVEMENT

A very simple intermittent movement is shown in the diagrams, as a matter of interest, for it has been superseded by the more advanced methods to be described shortly.

The sprocket roller, D, turns continuously. The pin, A, strikes the film as it is on the point of tightening owing to the operation of the roller, G, and jerks it ahead. This is the instant when the shutter hides the picture, or rather shuts it off from the screen.

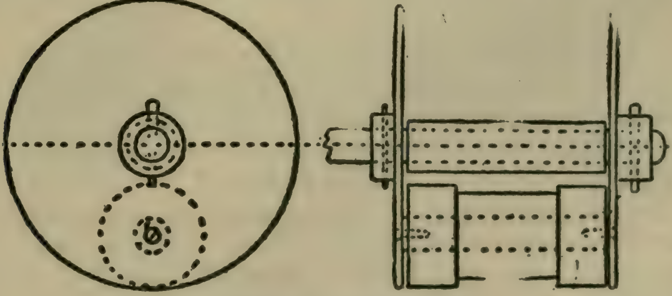
There is an idler provided, a roller, which is used to adjust the operation of the intermittent movement. It may be moved to other positions, which change accelerates the movement of the film for the instant, so as to advance the closing point.

Simple and primitive as this appliance may seem it has been in use in projection apparatus extensively. It is called the dog movement.



THE DOG MOVEMENT

At first sight it might be thought to have the advantage of not acting on the film sprocket holes. This, however, is only apparent.



ROLLER DOG MOVEMENT

The pin, A, does not act directly on the holes in the film; it only strikes its back or surface. But in doing this it works against the hold of the sprocket, D, on the film, and thus puts the pull upon the holes in question, and straining them as much or more than the more mechanical methods of intermittent movement now in use by the larger companies.

It is said that the dog movement was so popular that the cinematograph world was divided into two camps, one dog and the other Geneva.

The dog movement is considered noisy and so violent as to give a shaky picture on the screen. Its extreme simplicity and freedom from ill effects from wear made it popular. It only had to strike a blow, there was no need of a close fit as in the more refined movements now in use by our larger makers.

In some of the dog movements the striking pin on the rotating disc is so set that it can be adjusted inwards or outwards, so as to secure perfect action.

Advantages and Disadvantages of the Dog Movement

The dog movement is considered to be comparitively free from straining the perforations. Its blow or push is distributed over the whole width of the film. This on its face seems a good feature, but the push of the dog is exerted against the perforations as the film is held more or less tight across the space between the gate and sprocket roller. It is said that a film with worn perforations will run fairly well with a dog movement, when it would be quite irregular in action with a movement depending directly on the perforations.

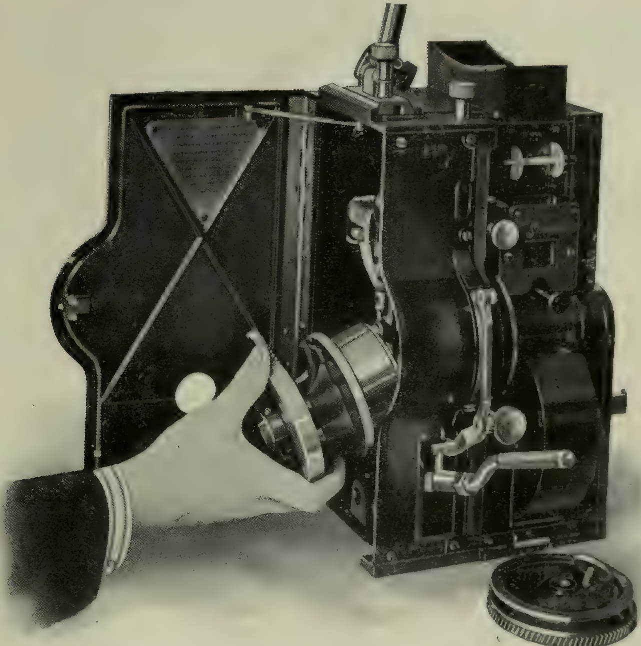
Film Shrinkage and the Dog Movement

The distance between gate and lower sprocket emphasizes the trouble due to shrinkage if such has occurred. It is said that it may multiply errors from shrinkage by nine or ten times the actual amount as far as the picture is concerned.

A very important feature of the dog movement is that the ratio of exposure to the obscuring depends on the diameter of the wheel carrying the dog, or more accurately expressed on the radius of the circle described by the dog or striking pin. The greater this radius the shorter will the period of obscurity be. In the early days of the art, the wheel was made quite large and the period of obscurity was so reduced that attempts were made to work without a rotary shutter, relying on the very quick shift with comparatively long projection period to give the effect.

The blow from the striking pin was found to be so violent that it broke the film and the attempt was abandoned.

For perfect operation the dog movement is very dependent on the accuracy of the teeth on the lower sprocket and on the accuracy also of the gears between itself and the lower sprocket. The point is that any variation in the length of loop or tightness of film, where the pin strikes it, and any error in synchronism between sprocket and dog wheel action will go to produce flickering on the screen.

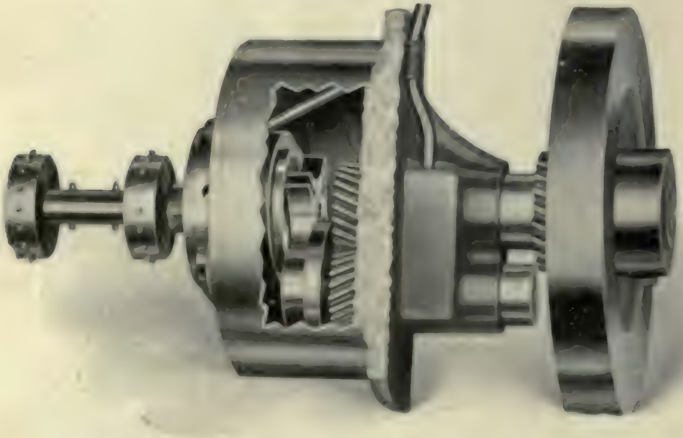


REMOVING SIMPLEX INTERMITTENT

Like the claw movement there is here no locking of the film in position for the projection. We shall see in the Maltese cross or Geneva movement, and in the Powers movement, that this locking is provided.

The Plunger Movement

The plunger movement is a variation on the dog movement. The striking pin is carried at the end of a pitman or connecting rod, which is driven to and fro by a driving wheel with a crank pin. The action is quite comparable to the dog action, but seems a little more mechanical and more in the nature of a push, and less like a blow.



SIMPLEX INTERMITTENT ASSEMBLY. THE GENEVA CROSS IS SEEN WITHIN THE CASE

The Geneva Movement

The Geneva movement takes its name from the Swiss city on the shores of Lake Leman. In Swiss watches there is a stop arrangement which mechanically arrests the winding when the spring is completely wound. This is called the stop movement, and it is what we rely on to prevent us from overwinding our watches and perhaps breaking the spring. Such a stop mechanism is common in clocks. One particular type is identified with the city in question, Geneva, and was used in Geneva watches. This gives it its name of the Geneva intermittent movement. As one of its members is more or less like a Maltese cross in shape, it is sometimes called the maltese cross or M. C. movement. It is a great favorite in this country and is much used in England.

The essential parts of the movement are two wheels; one is a disc carrying a single pin near its circumference; the other is a sort of cross with slotted arms, so shaped that when not turning, it rests against the disc wheel and is locked in position.

The projection period and obscure period ratio may vary from one to four up to one to six, according to proportions of parts.

WEAR IN THE GENEVA MOVEMENT

To insure perfect action and perfect locking the parts must fit snugly. Naturally they are made of steel of a quality to last well and to wear slowly. To prevent wear, which would be rapid without lubrication, the two wheels are enclosed in an oil-bath, for this is what the case in which they are contained really is. In the large cut the intermittent mechanism is shown; the case inclosing the two wheels is partly broken away in the cut to show the interior; the cross-wheel can be seen there. This case is charged with oil, so as to keep the wheels practically immersed in oil. Even at this there is a little wear to be anticipated. An eccentric bushing is provided for adjustment and for taking up any wear.

The wear, however, is so slight, owing to the oil bath, that the adjusting bushing needs but seldom to be touched, once the parts are in place.

GENEVA MOVEMENT OF THE SIMPLEX PROJECTING MACHINE

The diagrams showing the operation of the movement indicate that the shafts of the two wheels are out of line. But by a pair of gear wheels, shown in the cut of the movement, which are to be seen within the case, the outside driving shaft and the intermittent sprocket shaft are brought into line with each other. The gear wheels in the cut are shown inside the oil bath, to the right of the driving-wheel and cross-wheel. Their relations are very clear in this cut. The gear-wheels also revolve in oil, in the same oil with the others.

On the left of the case will be seen in the same cut the intermittent sprocket with its sixteen teeth on each end.

The cuts and description refer particularly to the Geneva movement as installed in the projection machines of the Simplex apparatus. We are indebted to the Precision Machine Co. of this city for the illustrations, which show so clearly the operation and disposition of parts.

THE PAUL INTERMITTENT MOVEMENT

We often in the early history of projection meet the name of the English constructor of projection machines, Robert W. Paul. To him is credited much of the early work in the development of the subject in England.

THE OIL BATH IN THE GENEVA MOVEMENT

Great accuracy of construction is essential to the Geneva mechanism or it will give bad results. To protect it from wear it is now enclosed in an oil-bath. If well constructed and kept in condition by the oil-bath it can be used up to almost a ratio of six to one of projection period to obscuring.

REQUIREMENTS OF THE GENEVA MOVEMENT

There are two requirements of the Geneva intermittent movement as used in moving picture projection. A shaft rotating at uniform speed must turn a second shaft through a part of a revolution, usually one quarter of a revolution, for each complete revolution of its own.

The second shaft must also be held rigidly motionless, except for the period of its partial turning. The intermittent feed of the film is effected by the second shaft operating the intermittent sprocket. While the shaft remains fixed in position the picture is projected on the screen. As the first or driving shaft rotates it reaches a point in its rotation where it engages with the intermittent shaft. It turns it through one-quarter of a revolution, and then locks it, so that it remains fixed for the rest of the revolution of the driving wheel. During this period of action on the intermittent wheel, the shutter comes into play and interposes one of its wings between the film and the screen.

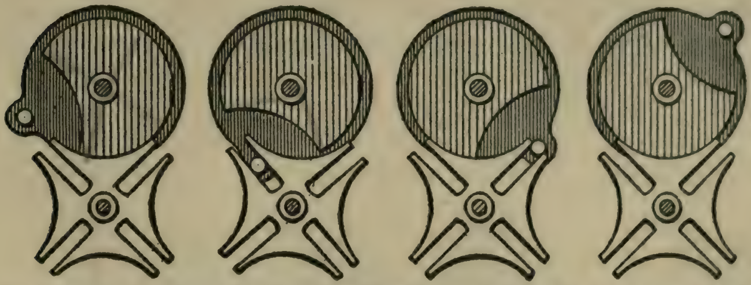
The action of the Geneva movement it will be seen is two-fold; it locks the intermittent shaft in position for about three-quarters of each of its revolutions; then it turns it through ninety degrees, which is one-quarter of a turn, and immediately locks it fast again for the three-quarters of its own revolution.

DETAILS OF THE GENEVA MOVEMENT

The illustrations show the principle upon which this movement operates.

The driving wheel is seen to the right of the star-like or cross-like wheel on the intermittent shaft. A pin is carried by a disc, so as to project from its face. A cylinder, cut away at one place as shown, and concentric with the disc, and inside the circle described by the pin in its rotation, is shown in black in the cuts. Each of the four arms of the star-wheel has a radial slot, of width to receive the pin on the disc of the driving wheel.

The contour of the cross-wheel between the arms is composed of four arcs of circles, each of a radius exactly the same as that of the cylindrical projection on the disc. When the cross-wheel is in place it fits snugly against the cylinder and cannot move; it is locked.



THE GENEVA INTERMITTENT MOVEMENT. FOUR OF THE POSITIONS ASSUMED BY THE MALTESE CROSS DURING ONE ROTATION OF THE DRIVING WHEEL

Then as the driving wheel turns the pin comes around and enters the slot in one of the arms of the cross-wheel as seen in the cut. The cross-wheel is turned by this pin; it is able to turn because the break or intermission on the cylinder causes the locking action to cease. The cross-wheel then turns under the action of the pin, as will be understood from the diagram, the pin next leaves the slot as the driving wheel keeps on turning and the cross wheel is again locked as shown.

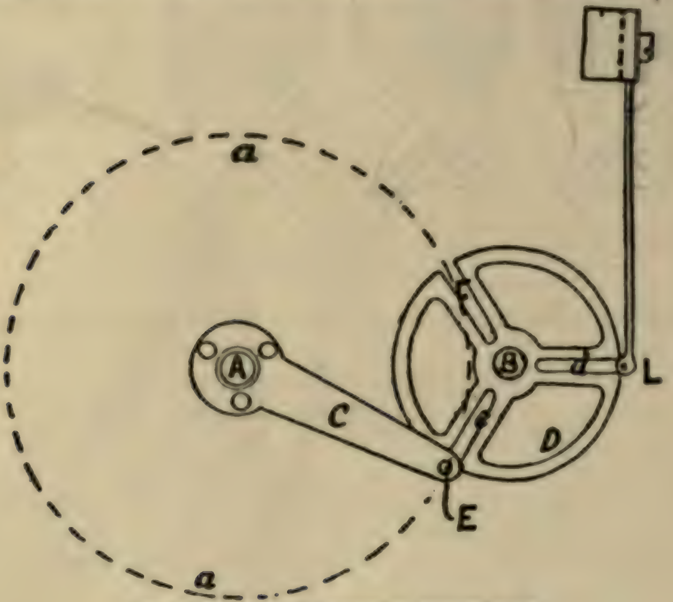
This is repeated for each rotation of the driving-wheel; a quarter turn of the cross-wheel is succeeded or followed by a locking of the same for the next three-quarter rotation of the driving-wheel.

Accuracy of Parts of the Geneva Movement

While it is evident that the accuracy of contour must be practically perfect, it will be seen that this is easily secured, because the parts which have to fit each other in the interlocking motions are arcs of circles or straight slots. This omits mention of the pin; that this must be of such diameter as to fit the slot is too obvious to require mention.

The illustration shows a modification of the Geneva intermittent movement. The peculiar locking feature of the four armed Geneva is missing here, and the lock depends on another principle.

The cross is done away with, and in its place there is a three armed wheel, with slotted arms, in this respect the same as the Maltese cross of the Geneva mechanism. The driving shaft is indicated by the letter, A. It carries an arm, C, which rotates at an even speed, and on the outer end of this arm is a pin and roller, E. As C rotates, the roller on its end enters the slot in one of the arms of the driven wheel. This slot in the inactive period is tangential to the circle followed by the roller, E. It gradually



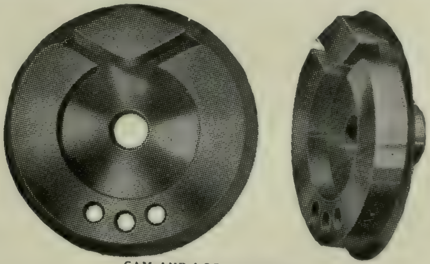
THE PAUL INTERMITTENT MOVEMENT

starts the driven wheel into motion, turns it through one-third of a turn and then the roller leaves the slot. In the drawing the arm, C, is supposed to be turning counter-clockwise, against the direction of movement of the hands of a watch.

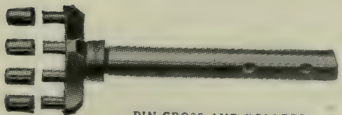
When the roller leaves the slot after turning the wheel, D, through 120°, the slot which it is leaving is left tangential to the circle, a, a, a. The next slot also is left tangential to the same circle, and is in position to be acted on by the arm, C, and roller, E, on the next rotation of the shaft, A. This rotation is not a full one as we have followed the arm, C, through part of a rotation, from its entering to its leaving the slot in the wheel, D.

THE POWER INTERMITTENT MOVEMENT

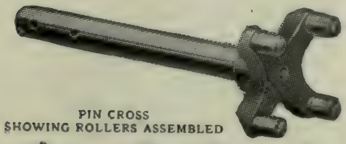
Power's Intermittent Movement is a departure from the well known Geneva movement. It produces a very perfect intermittent



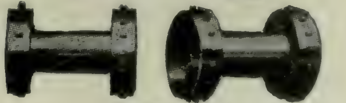
CAM AND LOCKING RING



PIN CROSS AND ROLLERS



PIN CROSS
SHOWING ROLLERS ASSEMBLED



SPROCKET

PHOTOGRAPHIC ILLUSTRATION OF COMPONENT PARTS OF POWER'S INTERMITTENT MOVEMENT motion of the feeding sprocket shaft. For the projection period the shaft is held rigidly locked; when the shift is to take place the shaft is caused to start its rotation almost imperceptibly, it reaches a maximum of speed and then is brought by even gradation to rest and is held stationary for the next exposure on the screen.

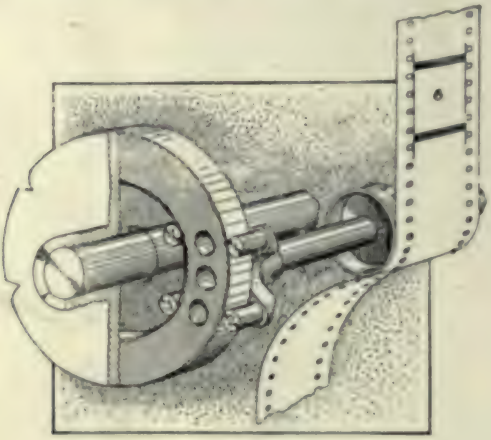


Fig. A

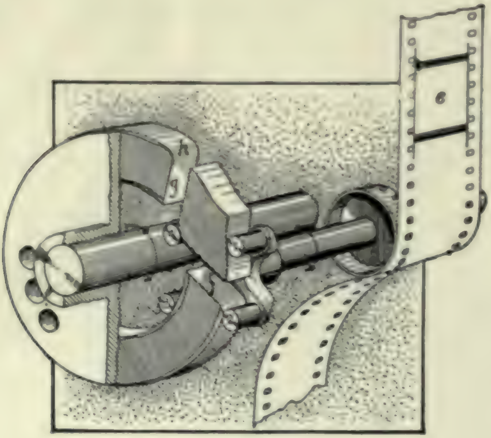


Fig. B

On the end of a shaft, which forms an extension or prolongation of the shaft of the sprocket roller, is mounted a four armed cross, from which four pins project, each spaced 90° from its neighbor. Each pin carries a chrome steel roller, to reduce fric-

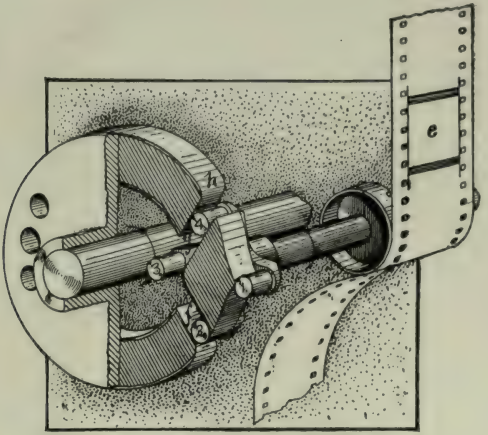


Fig. C

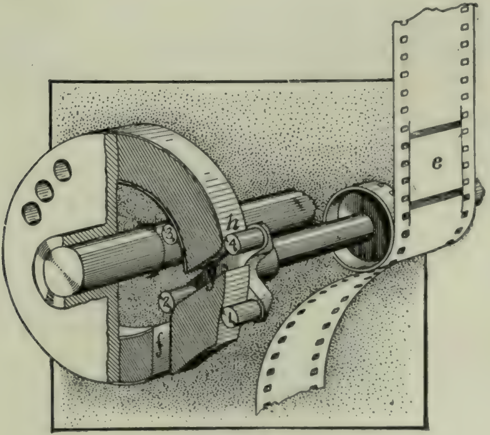


Fig. D

tion and secure prolonged enduring qualities. The rotation of the sprocket shaft is effected by the action of a cam upon these four pins.

THE PIN CROSS IN THE POWERS MOVEMENT

The technical name for the cross with its pins is the pin cross.

Facing the pin cross is a disc something over twice its diameter, and to the face of this disc is fastened a steel ring, broken at one place, where the interval contains a cam of a diamond shape. Imagine now the pin cross so placed that two of the pins are inside the ring, and the opposite two outside the ring, and fitting snugly without any shake. It is obvious that the pin cross cannot revolve as long as the pins are thus held by the ring, and it is also clear that the ring can turn without affecting the locking of the pin cross in position.

Perspective views of the locking ring and of the cam are given here; the solid construction is brought out, as well as the simplicity. It will be seen that the cam projects a little outside of the outer circle of the locking ring. This slight projection is an essential feature of the apparatus.

The pin cross is shown in the same set of cuts along with a sprocket roller. The anti-friction rollers are shown in one view off and in the other view on the four pins. When all parts are in place the ends of the pin rollers come against the face of the cam and locking ring disc, which effectively holds the pins in place.

We now turn to the four diagrams of the action of the cam and locking ring on the pin cross, and on the motion of the shaft of the sprocket.

Figure A shows the pin cross in the locked position, part of the cam and locking ring disc being omitted from the diagrams to show the entire operation. This cut shows clearly the locking action. It will be understood that the disc is turning constantly at a regular unvarying speed.

BALANCE IN THE POWER INTERMITTENT MOVEMENT

The three holes near the outer surface of the locking ring are only to secure an even balance. If sixteen projections a second are given, the locking ring and cam must rotate sixteen times a second also, as each rotation produces one shift of the film.

The portion of the film marked e, is supposed to represent one of the film pictures to be projected.

As the disc rotates the film is held motionless and the picture is shown on the screen.

When the position of figure B is reached the outer point of the diamond-shaped cam begins to come into contact with the pin 1. The pin is pushed forward and upward. On reference to the perspective views the rounding of one corner of the locking ring and of the lower corner of the cam will be seen; this rounding facilitates a smooth movement of the pin cross in its rotation.

As we look at this disc it is rotating in the direction of the hands of a watch. As pin 1 is pushed along pin 2 begins to enter the slot f, as shown in figure C. The sprocket is now turning and the picture e, is being drawn out of the frame downwards.

Finally figure D is reached. Here pin 4 has emerged from slot h; pin 1 has been moved to the position formerly held by pin 2, the cam passes on out of engagement with the pins and the pin cross is locked at an angle of 90° with its position before the cam acted on it.

As there are sixteen teeth on the sprockets and four apertures for each picture, this quarter rotation advances the film exactly one picture.

During the period of the quarter rotation of the pin cross and consequently of the sprocket the revolving shutter shuts off the picture from the screen.

The relation of the practically straight sides of the cam to the rotating of the locking ring gives a perfectly circular path for the pins of the pin cross to follow as each one in its turn moves through the slots.

The rotary motion is most accelerated as the pin (in the diagram pin 1) passes over the top of the diamond. It starts slowly and ceases its motion slowly. This is a great saving of the film, as anything resembling a jerky motion tends to tear it and to impair the perforations. Especially is a jerky motion hard on a film if it has been repaired or is starting to tear.

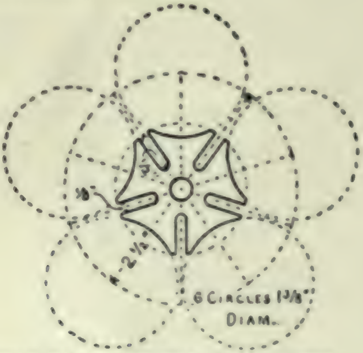
Care of Powers's Intermittent Movement

It is sometimes necessary to open this oil reservoir, for inspection or replacement of parts. To replace the cover proceed as follows: The edges of the cover will be coated more or less completely with old shellac. This must be removed by scraping, light rather than heavy. The idea is to remove the old shellac without scratching or impairing the metal surface. More or less of the shellac will be left on the edge of the oil reservoir; this must also be lightly scraped like the cover.

Then a coating of thick shellac is spread upon the edge of the cover, not on the oil reservoir. It is allowed to stand a while so as to thicken a little; it must not be kept long enough to become hard. As soon as it seems thick enough to have a good body, the cover is applied and is screwed fast. Do not use too much shellac. Too much shellac will sometimes cause some to get into the intermittent mechanism and it may do serious harm. The breakage of the pins of the Geneva movement has been attributed to shellac getting into the mechanism.

Flicker and the Intermittent Movement

In the intermittent mechanism the cam turns constantly at a uniform speed, one revolution for each picture projected. The cross has to come to rest, remain so a fraction of a second, then be turned through 90°, all with considerable rapidity. The stoppage and the turning of the cross must occupy about the sixteenth of a second. There must be no lost motion and no friction. The absence of flicker is largely dependent on the operation of the intermittent movement. It should run in oil with the greatest possible smoothness, and particles of a foreign substance such as shellac should be absolutely excluded.

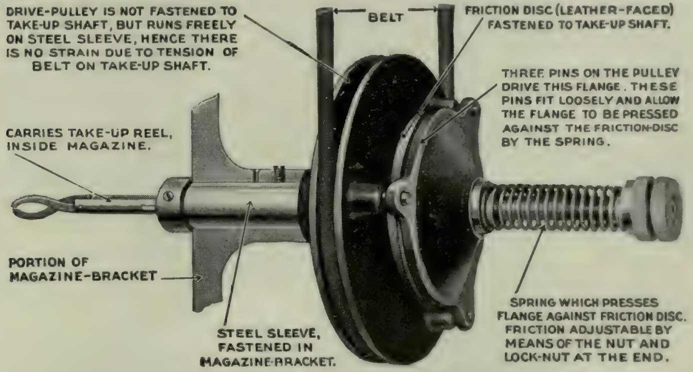


FIVE PART GENEVA MOVEMENT

CHAPTER XIII.

THE TAKE-UP

AS the film comes out at the bottom of the feeding mechanism of the projection apparatus, it has to be wound on the lower reel. Otherwise the thousand feet of film, usually to be disposed of would be unmanageable. To effect this winding the film reel has to be positively turned. In the case of the upper reel all that is to be done is to draw the film off it by the action of the sprocket mechanism. The upper reel is idle.


DRIVE-PULLEY IS NOT FASTENED TO TAKE-UP SHAFT, BUT RUNS FREELY ON STEEL SLEEVE, HENCE THERE IS NO STRAIN DUE TO TENSION OF BELT ON TAKE-UP SHAFT.
BELT
FRICTION DISC (LEATHER-FACED) FASTENED TO TAKE-UP SHAFT.
THREE PINS ON THE PULLEY DRIVE THIS FLANGE. THESE PINS FIT LOOSELY AND ALLOW THE FLANGE TO BE PRESSED AGAINST THE FRICTION-DISC BY THE SPRING.
CARRIES TAKE-UP REEL, INSIDE MAGAZINE.
PORTION OF MAGAZINE-BRACKET
STEEL SLEEVE, FASTENED IN MAGAZINE-BRACKET.
SPRING WHICH PRESSES FLANGE AGAINST FRICTION DISC. FRICTION ADJUSTABLE BY MEANS OF THE NUT AND LOCK-NUT AT THE END.

TAKE-UP MECHANISM OF THE SIMPLEX PROJECTOR

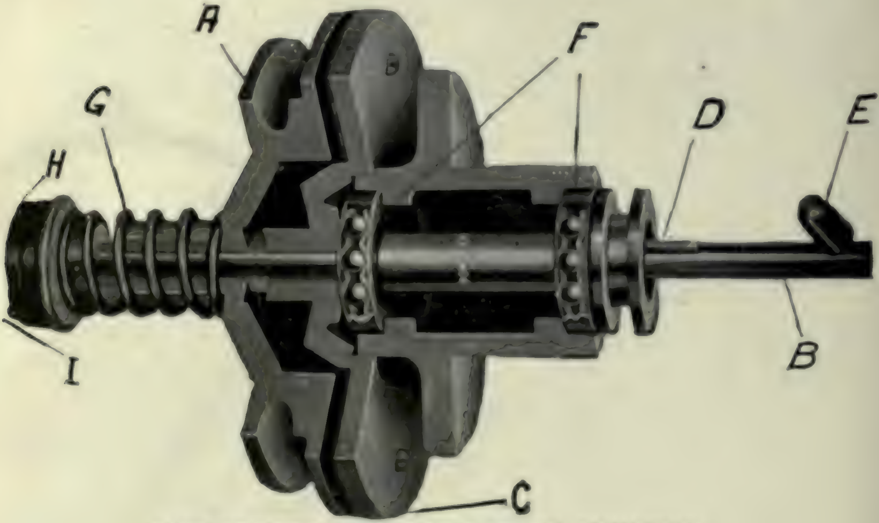
A moment's consideration will show that if the lower reel were turned at an unvarying speed, it would not take up the film evenly. At first when the reel was empty the diameter of the drum would be so small that the film would be wound up slowly. Then as the roll of film on the drum increased in amount, so as to virtually form a drum of constantly increasing thickness, the film would reel up more and more rapidly.

THE TAKE-UP IN THE SIMPLEX MACHINE

It is obvious that the simplest way to avoid this difficulty is to turn the lower reel with varying speed. The Simplex machine employs a way of doing this which depends for its action upon a flat-faced friction clutch. It is clearly illustrated in the cut.

The large drive wheel shown with a belt encircling it, is turned at a speed as regular as possible, and following exactly the rotation of the rest of the mechanism. It is carried by a thick tubular shaft, which in the cut is shown extending to the left, and enclosed in a bearing carried on the frame of the machine. This bearing takes the whole weight of the drive wheel and of the strain of the driving.

Through the hole in the tubular shaft just described, the comparatively light shaft of the lower reel extends. The reel is pushed on the end of the lighter shaft, on the left end as shown in the cut. A catch arrangement is provided to hold it on and to fix it so that it will turn with the shaft.



TAKE-UP MECHANISM OF THE POWER PROJECTOR

On the right of the driving wheel are seen two discs. The outer or right hand one is supported by three pins, on which it can slide in and out, towards and away from the drive-wheel. It has to turn with it, owing to the three pins. On the smaller reel shaft, where it comes through the shaft of the drive-wheel, to the right in the cut, there is fastened to it another disc, facing the first described one. This second disc has to turn with the reel-shaft, and cannot shift back and forth like the other disc. The face of it is lined with leather.

On a long extension of the inner or reel-shaft to the right in the cut, a spring is placed, with an adjusting nut at the outer end of the same shaft. This presses the outer shifting disc against the leather faced surface of the fixed disc, constituting a friction clutch. As the drive-wheel turns it turns the inner shaft by the friction between the discs. This is made greater or less by the adjusting screw, so that the clutch will slip as it operates and in this way will turn the reel more and more slowly as the accumulation of film upon it increases the diameter of the roll.

Requirements of the Take-Up Mechanism

The case of the take-up mechanism is thus put by its devisers:

"(1) it must never fail, but always take up the film as fast as the mechanism pays it out, and (2) it must unfailingly slip, for too strong a pull will injure the sprocket-holes in the film."

The Take-Up in the Power Machine

The Power take-up comprises two discs, facing each other, one of which is lined with fibre so as to give a friction surface. The two discs are pressed together by a spiral spring.

The disc, A, of the cut is the driving disc, and it is free to turn on the take-up spindle, B, which acts as its shaft. The driven disc, C, is fastened to the shaft or spindle, B. Thus as the frictional contact between the two discs, causes the rotation of the driving disc to be imparted to the driven disc by friction only, it is clear that there is no rigid contact, and that the driving disc can turn much more rapidly than the driven one, the discs slipping so that one turns slower than the other. The one, which turns at constant speed is the driving disc; the driven disc can be caused to turn as slowly as desired by reducing the friction between it and its actuating disc. This friction is regulated by the spiral spring. If this is set at slight tension the friction will be reduced and the condition will be established for considerable variation in the speed of rotation of the discs.

Of course they would turn at the same speed under any conditions of friction if there were no strain on the driven disc.

But a strain is put on the turning of this disc by the slight drag of the film. It therefore lags a little in its rotation and in this way takes up the slack of the film.

The lower reel is thrust on the right hand end of the spindle, B, so that it and the disc, C, turn together. The tension of the spring, G, is regulated by the threaded collar, H, which is set to give the proper tension and is locked by the set-screw, I.

On the right hand end of the spindle is a catch, E, which, when turned down, comes in line with the spindle, B, so that the reel can be slipped into place on it; then by turning the catch into the position shown in the cut the reel is secured on the spindle. The spindle turns in ball bearings, F, spaced well apart, so as to give good support and ensure free action.

The degree or amount of tension to give the spring is defined as barely enough to turn the reel when it is full of film, that is, when it is at its greatest diameter of roll.

THE FUNCTIONS OF THE TAKE-UP

It will be seen that there is quite a problem to be solved here; a constant feed is to be maintained by a uniform rotation of a feed roll of gradually increasing diameter. In the take-up mechanisms we are describing, it is done by letting the feed roll slip on its spindle, so as to do away with its uniformity of rotation. The steadily increasing work the reel has to do, owing to the increase of diameter brought about by the accumulation on it of the film, retards the rate of rotation more and more, automatically regulating the revolutions of the take-up reel, and keeping a fairly constant tension on the film, or more properly a constant rate of winding on the reel.

THE LOWER LOOP

As the intermittent sprocket draws the film, with its sixteen pulls per minute in standard running through the plane of exposure, or the frame, the film fed downwards is taken up by another sprocket and fed to the lower reel.

It is essential that the film should be subjected to no longitudinal strain. It is fed freely to the intermittent sprocket; this passes it across the field without having to pull it except in the lightest possible way; then it must be reeled up without strain, and yet must be taken out of the way so as not to accumulate in the machine.

A lower sprocket, not working intermittently, feeds the film along towards the lower reel, which winds it up and thus it is disposed of. To prevent any strain an excess of a few inches of film is put between the intermittent and the lower sprockets and this droops down and forms a loop. This loop is shown in the illustration.

Loosing the Loop

As long as the loop is there the film will go through the apparatus without strain, and the slack, which the loop secures will avoid all possibility of injury to the sprocket holes in the two margins of the film. If the loop should disappear, or in the usual terminology be lost, the film is at once put under a strain and damage is liable to ensue.

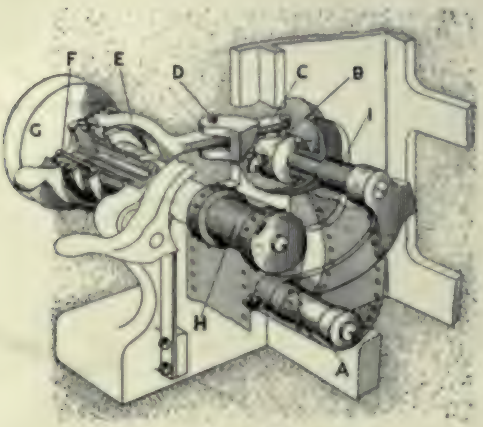
All three sprockets are of the same diameter, and as far as their size is concerned will feed the film so evenly one with another, that if the loop is once formed it would persist. But the film may not lie as close to one sprocket as to the other. This will occasion a variation in the rate of feed, and if it is the lower sprocket, which the film lies loosely on, the loop will soon be lost and the film will be subject to strain.

Power's Loop Setter

The cut shows a mechanism designed to secure the loop under all conditions. It is the Powers Automatic Loop Setter.

G is the driving pulley turning the take-up or lower sprocket, H. The film is seen with its loop; within the loop is the roller, A. If the loop becomes tightened up, it will draw the roller, A, upwards, because this roller is mounted on the end of an arm attached to a shaft, which is seen back of and to the right of the lower sprocket. If the roller, A, rises it turns this shaft. The cylinder, B, on the same shaft turns with it, and a pin connected to an arm, C, which pin is within a diagonal slot in B, is caused to move a short distance in the line of the shaft. This moves the arm, C, which is pivotted at D, so that its end, E, moves towards the right, as shown in the cut, and draws the pin, F, back and out of contact with the driving pulley, G. But this pin is the only connection between the lower sprocket, H, and the driving pulley.

Accordingly when the loop begins to be lost, the pin, F, is drawn back, and for an instant the lower sprocket ceases to turn, the loop instantly forms and the roller, A, drops a little. The pin, F, again comes in contact with the driving pulley and the lower sprocket resumes its take-up or feeding action.



POWER'S LOOP SETTER

In addition to the diagram or outline cut showing the operation of the loop-setter, we give a general view, which shows the relation of the apparatus to the projector. Directly under the center of the projector the loop-setter roller is shown in dark tint, and just above it in phantom or light tint is the lower sprocket roller. The clutch mechanism on which it depends for its action is on the right hand of the cut, and is also shown in dark tint.

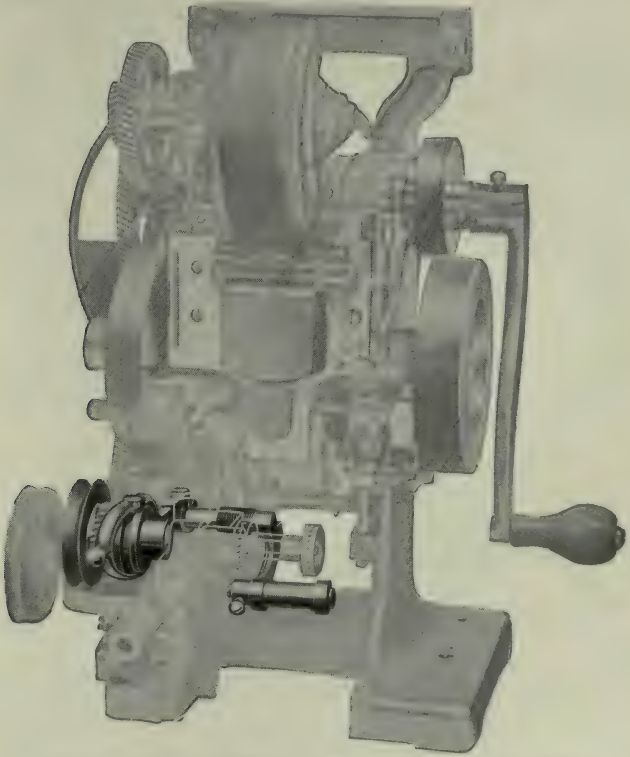
THE POWERS SPEED CONTROL

When the take-up mechanism operates in conjunction with the loop-setter, all danger of straining and pulling at the film is pretty well done away with.

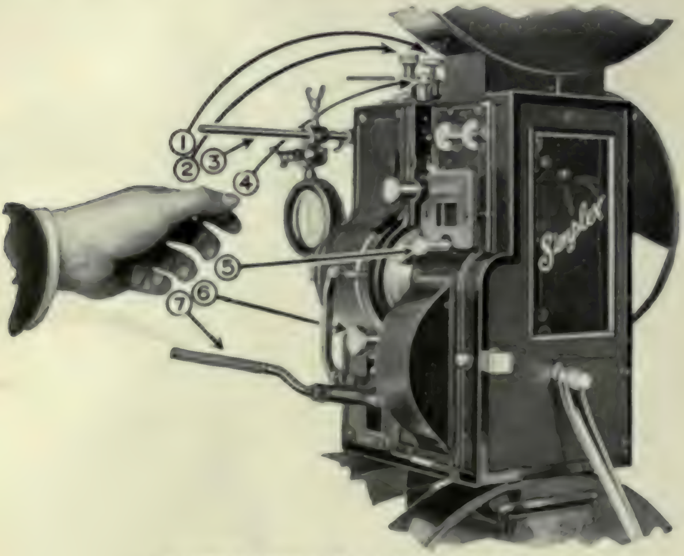
The Power Speed control is based on the action of a centrifugal governor, which changes the pressure of one friction wheel against the other. These wheels are arranged face to face, being carried on the same shaft with the pulley which drives the projection machinery as well as the driven pulley.

Referring to the illustration the driving pulley is seen at the outer end of the shaft to the extreme right. This pulley is belted to the electric motor and is turned at an invariable and constant speed.

Immediately to the left of the driving pulley are seen the two friction wheels, situated face to face. The right hand one, the one nearest the driving pulley is fixed to the shaft. The other friction pulley is disconnected from the shaft and is free to turn on it. In one piece with this left hand friction wheel is the driving pulley, which by a belt drives the machinery of the pro-



POWER'S HEAD SHOWING AUTOMATIC LOOP-SETTER jector. We next see the centrifugal governor, within the case of the instrument. This is so geared that if the shaft turns too fast the weighted arms of the governor move outward and draw the left-hand friction wheel of the friction element to the left.

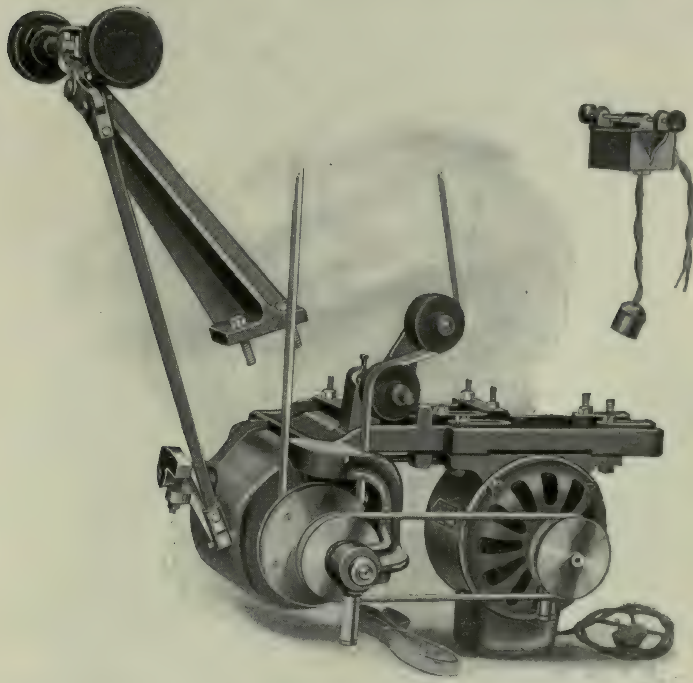


ADJUSTMENTS ON SIMPLEX HEAD
1, 2, 3. All stereopticon adjustments
4. Focusing Projection Lens
5. Door to Lower Loop
6. Adjusting the Shutter
7. Framing

This diminishes the pressure between the two friction wheels and the driving force is reduced, and one of the wheels slides or slips around, so as to reduce the speed of the driving pulley. This is the second place where a frictional slipping contact operates in the movement of the machine.

Hand Control in the Power Speed Control

There is a hand control with two handles on the upper end of a bracket, so as to bring them at a convenient height to be reached by the hand. By this the tension on the governor spring, seen within the case surrounding the shaft, is varied so as to cause the governor to act more or less on the friction wheels. The more the spring is compressed the friction discs or wheels will be pressed together by the spring and the governor will have less effect in reducing the frictional pressure between the faces of the same wheels. The effect of this will be to increase the speed of rotation of the driving pulley, and consequently of the reels.



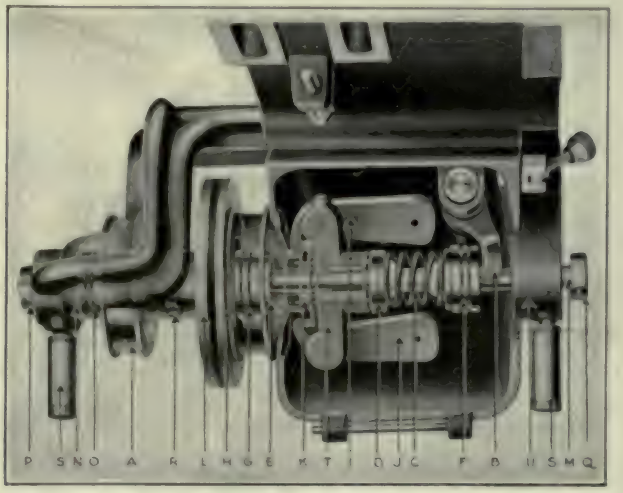
POWER'S CENTRIFUGAL GOVERNOR SPEED CONTROL OR MOTOR DRIVE

By this mechanism the speed of projection is kept the same, as long as the hand control is not used. If the character of the pictures requires a higher speed, so that the action shall be accelerated a turn of the wheel on the top of the bracket will change the speed as desired.

In the Power machine in all parts, where it is desirable, there are handles at the right and left for the same adjustments. The idea is to provide the greatest convenience of operation, so that the operator will not have to pass his arm around the machine to get at an adjusting handle. Accordingly there are two handles on the bracket for regulating the speed, so that the governor can be regulated with the left or right hand or from either side of the machine with equal facility.

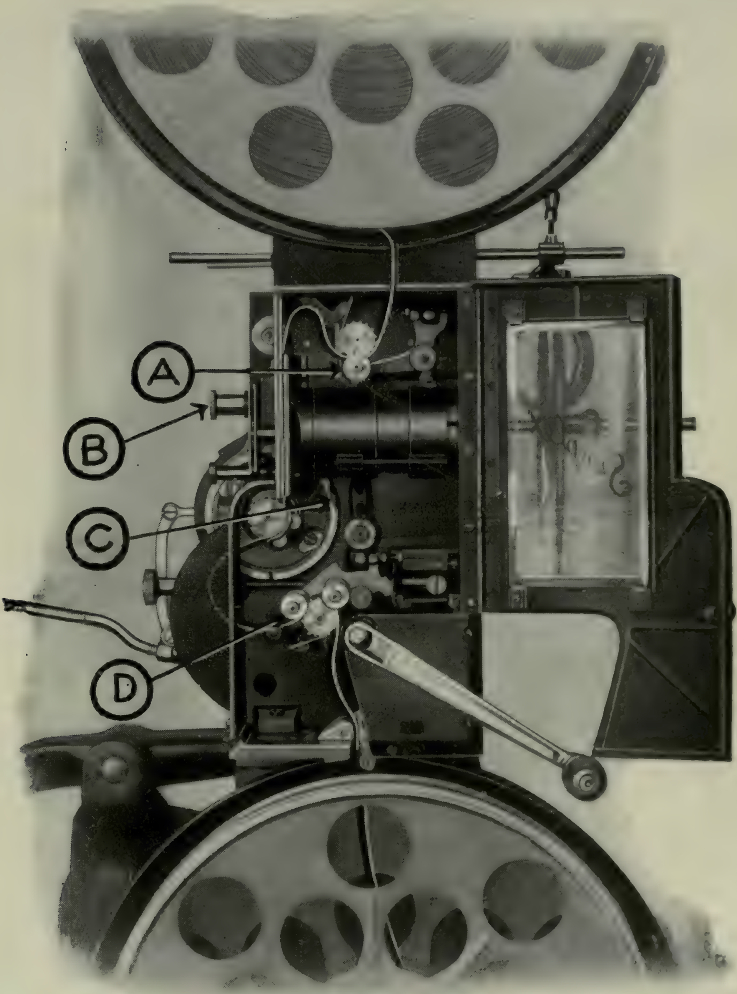
Range of Action of the Power Speed Control

The speed of rotation of the machine is referable to the crank-turns. By this driving control the crank speed, as it may be termed, may be made to vary within a fraction of a turn from thirty to one hundred and sixty turns a minute. This is of course a range far greater than could ever be needed; this is the range given by the constructors of the device.



MECHANISM OF POWER'S CENTRIFUGAL SPEED CONTROL OR MOTOR DRIVE

There is another thing to be noted as concerns this power of accurate speed control. It makes it possible to determine exactly how much time shall be given to a given reel. If its length is



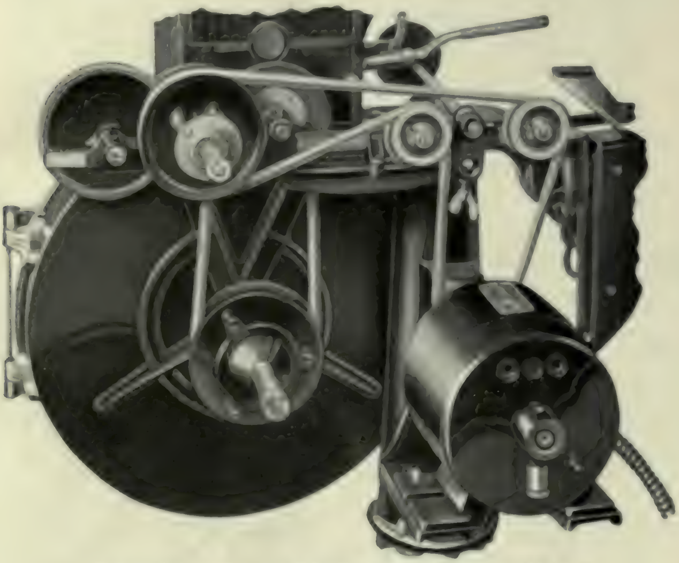
MECHANISM OF THE SIMPLEX PROJECTOR HEAD
A. Feed Sprocket Roller.
B. Gate Release.
C. Gate Lock.
D. Take-Up Sprocket Roller.

known it can be made to run any desired time by setting the governor spring for so many feet of film per minute.

SIMPLEX SPEED CONTROL

This appliance is designed for attachment to the projecting machine to secure an even rate of speed from an electric drive, and to make the hand regulation of the speed of the motor convenient and unfailing.

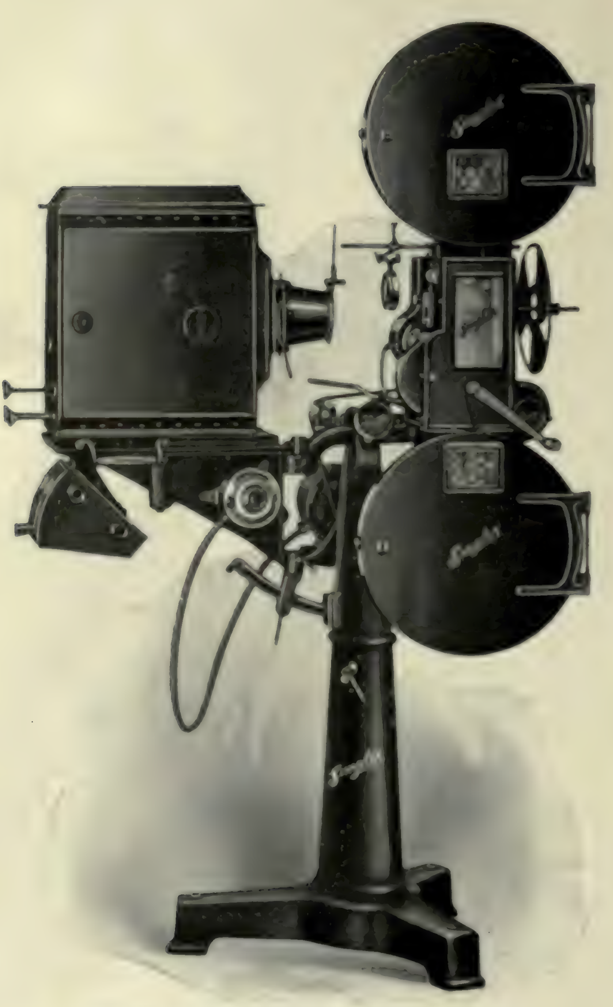
The general principle on which it works is the following: Two friction wheels face each other, but do not touch. A third wheel, which operates the mechanism of the projection machine and whose speed is controlled by the friction wheels, is carried on an axle parallel to that of the two friction wheels. By an adjusting wheel or handle, the third wheel, as it may be termed, can be forced in between the two friction wheels. The closer it gets to their axle, the slower will its motion be. If drawn out, so as to be near the periphery, it will rotate faster.



SIMPLEX SPEED CONTROL OR MOTOR DRIVE

Regulating Feature of the Simplex Speed Control

The motion of the mechanism is derived from an electric motor; this rotates at a constant speed. The projector then operates at an unvarying speed also. If it is desired to accelerate the rate of projection, the hand-wheel is turned so as to draw the third wheel outwards from the axle of the friction wheels. They turn under the action of the electric motor at a constant speed. The causing them to drive the third wheel with the portion of their faces nearer the periphery imparts a higher speed to the third wheel and therefore to the projecting mechanism. If the third wheel is pushed in further, it will be turned by a portion of the friction wheels nearer the center and hence of slower speed. The motor preserves a constant speed of the friction wheels all through the operation of the machine; the operator varies the speed by hand.



SIMPLEX PROJECTOR, MOTOR DRIVEN

CHAPTER XIV.

THE FILM

THE film, on which the pictures for motion picture projection are photographed, is made of celluloid. It is a sort of solution of a nitro-cellulose, a close relation to gun cotton, in camphor. It is very combustible, but hardly explosive unless under the most exceptional circumstances. The pictures on it are in an emulsion of gelatine. This is the substance of which glue is made; glue is very impure; the gelatine of the photograph emulsion on the film is as pure as it is possible to make it by the most elaborate processes and precautions. There is a certain amount of chemical substances mixed with the emulsion so that it will receive the photographic image. Gelatine is combustible, but in a very sluggish way. If you try to burn glue, you will find that while it will burn, it will do so without any energy or vigor.

INFLAMMABILITY OF THE FILM

Pure celluloid burns with considerable energy, a piece of film from which the gelatine coating has been removed will show how fast and how energetically it burns. The film, with its coating of photographic emulsion, burns less vigorously than the pure celluloid film does.

The film is now thoroughly standardized. It is 1 3/8 inch wide. On each foot there are sixteen pictures, no more and no less. On each side is a row of perforations. These are spaced with the most exact precision, for on the correct spacing of the perforations depends the perfection of the projected pictures.

THE PERFORATIONS

There are four holes at the side of each picture, so there are four times sixteen perforations, sixty-four perforations on a side to each foot of film. Other dispositions of the perforations have been used in past times, but the film is now absolutely standard.

In the early days of the art, in the last years of the nineteenth century, the famous French photographic house of Lumière moving picture projection apparatus, used the claw intermittent feed. This feed only needs, and can only use a single pair of perforations for each picture. The four perforations for each picture is designed for sprocket feed. The Lumière concern therefore made only one pair of perforations to each picture. More holes would have been useless. The perforations were spaced 20 millimeters apart, approximately 4/5 inch. This gave about fifteen pictures to the foot of film. This system of perforation had the advantage that it was stronger and more durable than the more numerous perforations in the Edison system. For the system of four perforations to the inch is credited to him. The Lumière factory also made round perforations.

Now the sprocket feed is universal, and the Lumière films of old days would not go through a modern projector.

Sir William Thomson, later Lord Kelvin, suggested that the perforations should be triangular in shape.

The original length of films was very much less than the present standard of one thousand feet. The French made them seventeen meters, about fifty-six feet long.

Winding of the Film on the Reels

The film is wound on reels, emulsion side out, and it is so wound that the beginning of the subject shall come out first. Otherwise every movement and the succession of events would be reversed. As the film is threaded through the machine, it must be done with the emulsion side towards the light. It is fed through the machine and wound upon another reel below the gate. On this reel it will be wound backwards. It must be rewound before it can be exhibited again. Unless some of the various non-rewind reels are used the operator has to rewind the film, to prepare it for the next exhibition. If it is to go back to the film exchange, it is often required that it be sent back without rewinding. The film supply house prefers to do this.

Repairing the Film

The film has to be joined or cemented together very often. In some cases it is because it has broken in two in the machine. In other cases the film has to have parts cut out, which are not wanted in the film as it is to be projected. The director may find much, which he feels is out of place in the drama.

FINDING DEFECTS IN THE FILM

Defects in a film, which call for mending, or for cutting and joining are looked for on a rewinding machine. The film is rewound, and as it passes from one reel to the other, it is passed through the fingers of one hand. Rough spots, where the film has been badly joined are easily detected by the feel; a joining, which is on the point of giving way is thus found.

MENDING A FILM

A joining should be so done as not to throw a single picture out of phase. This does sometimes occur, when the mending has been done by an incompetent or careless person. This defect is not found by feeling, and it is very hard to find by sight in the rewinding.

To mend a film it is necessary to sacrifice one picture. The film is cut through, using a straight edge or ruler, exactly on the edge of a picture. The other piece of film is cut through between the first and second holes and midway between them. The straight edge is now placed across the second piece of film, exactly on the edge of the picture, and the film outside the ruler is moistened with water, put on with a camel hair brush. This will soften the film, so that it can be rubbed off with a bit of rag, after the film has been cut through along the edge of the straight edge. This cut must be only enough to cut through the film, and the lightest possible pressure on the knife may be quite sufficient. A coating of film cement is now applied to the surface just cleaned, and it is quickly placed on the celluloid side of the other piece of film, and it is placed with the holes in exact register, one over the other. A tapering stick of wood, or better a metallic pointed wire or slender rod, like a scribe awl, may be used to insert in the two holes, first on one side and then on the other, to ensure their being in perfect correspondence and one on top of the other. The teeth of the sprockets have to go through every hole on the film, so it is absolutely essential that the two holes should correspond.

A film mender is a little press which holds the film in perfect registration as it is drying, and pressses the pieces together as they dry, so as to produce a flat mend.

FILM MENDING CEMENT

Care must be taken not to dirty the film in the handling. Scraps of film should be kept, if the operator proposes to make his own film cement. The films must be cleaned of the emulsion or gelatine by treatment with water, warm if necessary, and rubbing. The film in quantity enough to make a thick solution is dissolved in the following solvent:

Amyl Acetate	1 part by measure
Acetone	2 parts by measure

The best plan in most instances is probably to buy the cement ready made. The above is for the ordinary celluloid films; for non-inflammable films a special cement has to be used.

FILM BREAKING DURING THE PROJECTION

If a film breaks during an exhibition, it may be temporarily joined by a wire paper clip, or enough may be drawn down to the lower magazine to get a turn or two around the film on the reel. The ends may even be pinned together. Do not forget to remove the clip or pin and to join the ends with cement.

FILM MENDING MACHINE

A machine or press for mending films is shown in the illustration. A flat surface adapted to receive the film has pins projecting upwards from it. These pins are so spaced as to exactly correspond to the sprocket holes in the film. When the film is cut off square and prepared for cementing as described, it is placed in position with the pins passing through the sprocket holes. The hinged upper part is then brought down on the film, and the special press is applied to the cemented ends. By the use of this machine absolute accuracy is secured, and no time is wasted in fitting the parts together and in ensuring the line-up of the two parts being united.

A screw is provided, seen on the right of the machine to adjust the position of the pieces of the film and to ensure matching of the holes. As a guide or safeguard a short piece of film could be used with this screw to obtain a perfect spacing of the perforations. It is obvious that it is a great advance on doing the cementing by hand.

Film Cleaning Machine

Machines are made on the lines of rewinders to clean films. The apparatus is an addition to the regular rewinding machine. As the film is rewound it passes through a little apparatus secured to the base of the rewinder. It is a little box. In it are two brushes, between which the film is drawn. Then come two pads, which wipe it off.

Thus when the film is rewound it is cleaned as a part of the process. The pads are specially prepared and they are supplied by the hundred for renewal as the old ones are exhausted. Even if a film is scratched the removal of dirt improves it by making the scratches less conspicuous.

Film Rewinding Tables

Special metal tables are constructed for the rewinding of films, of which there are a number of varieties. The principal point in their construction is to avoid anything which might scratch a film as it was being rewound. In one table there are no rivetted joints, spot welding being used throughout to fasten the frame. Rivets would be liable to have projecting heads or ends, which might give trouble. In spot-welding the material of the frame is melted in spots together, which makes at once a very strong fastening, but also avoids all projecting joints.

Film Waxing Machine

In the rewinding operation there is an opportunity to wax the films along the line of the sprocket holes. This is a species of lubrication, which improves the running of the films, keeps oil from getting on them, and moderates the tension on the film caused by the feeding operation. The avoidance of tension of the film is conducive to its being kept in good condition and to its durability. The waxing is supposed to work to the advantage of the machine, by keeping it free from emulsion, which in the absence of this lubrication is apt to accumulate on the tension springs and aperture plate.

The appliance comprises a pair of brackets on a base plate. It is fastened on the base of the rewinding machine, and in the rewinding, the film passes under a roller, and then under and over the wax cylinders so as to get a coating of wax over the surface of the film on the line of the sprocket holes only. The cylinders can be adjusted by setting in or out, so as to wax the desired width of the film. The waxing is done on both sides.

FILM MEASURING MACHINE

The film measuring machine, a useful appliance, is a combination of a revolution counter with a sprocket wheel or roller. The film passes over the surface of the roller, the sprockets ensuring the absence of slip. The revolution counter is geared to give the reading of the feet of film, which pass, and when all the film has gone through the sprocket comes to instant rest.

When the end of a film is reached at the close of a projection, it will be transferred to the lower reel in the lower magazine. On this reel it is wound backward, so that it could not be put into the upper magazine and fed through the machine, as the action would go backwards. The film has to be rewound. This is done by winding it from this reel upon another one, it may be back upon the first one, from which it has just been unreeled as it was projected on the screen.

HAND AND ELECTRIC REWINDING MACHINES

There are a number of machines made for this purpose. Some are operated by hand turning, and others by an electric motor.

In the hand machine there are a winding bracket and a dummy bracket, the latter to hold the reel from which the film is to be removed. The winding bracket is provided with gears, so that the revolutions of the axle carrying the reel are multiplied. This makes the operation more rapid.

This is very simple, but to do the work with less manual exertion and to save time as well, the electric winding machine is better.

The illustrations show several constructions of electric rewinders. They are an object of inspection by the Fire Underwriters. They are supposed to be made of metal, so as to be incombustible. In one of the cuts a rewinder is shown, in which the film reels are enclosed in magazines during the rewinding operation.

FILM POLISHING MACHINE

A machine for polishing films is shown in the cut. The advantage of cleaning films has been spoken of. Every little scratch in a film shows on the screen. All the cleaning machine does is to clean the surface, as a clean crack will show less than one that is filled with dust or wax.

The polishing machine goes a step farther than the simple cleaner. The film is rewound on the machine, the film passing through the different parts and over the rollers of the machine in its course from one reel to the other. Each reel is contained in its magazine; the full reel feeds out its film and it is wound back into the other magazine. The tension is maintained so as to keep the film stretched just the right amount, yet so as not to strain it. The machine is run by a one-half horse power motor.

It is the emulsion side of the film, which is polished. The gelatine is very much softer than the celluloid, and is at once more liable to injury and easier to polish.

The film is first passed over felt rollers, which are moistened with cleaning fluid. The film next goes under felt buffing wheels, against which it is held by a metal wheel, so as to get the effect of the buffing without directly straining the film.

Buffing and idler wheels can all be removed by hand, without the use of tools. This facilitates renewal of the felts and cleaning in general. It requires from nine to twelve minutes to polish a full reel, one thousand feet, of film.

The Perforations of the Film and Their Determination

The perforations of the film, as regards their longitudinal distance from each other is based on the diameter of the sprocket rollers. These are turned with the utmost accuracy on the two ends; the center is turned down, so that the effective diameter of the rollers is that of the disc-like ends. Around these ends the sixteen sprockets are evenly spaced. The holes in the film must match the distance between contiguous sprocket teeth. The diameter of the sprocket is fifteen-sixteenth of an inch; this gives a circumference of 2.94525 inches.

The thickness of the coated and developed film is taken at .0065 inch. This added to the diameter of the sprocket gives a pitch circle of 0.944. This the sum of the diameter of the sprocket, .9375 + .0065; .9375 is the decimal expression of fifteen-sixteenths of an inch. The circle corresponding to this diameter is 2.96567 inches, and the sixteenth part of this is .1853 inch. This is the distance from sprocket tooth to sprocket tooth, because there are sixteen teeth on the circumference of the sprocket. These considerations determine the lay out of the sprocket teeth. We now come to the film.

A pitch circle of 2.96567 multiplied by four, as there are four circumferences of the sprocket pitch circle in a so-called foot of film, gives a length of 11.86268 inches. In this length the sixty-four holes or perforations are to be made.

Such are the general considerations regulating the perforating of films. The point to be remembered is that it is the diameter of the sprockets which fixes the film length for the sixty-four perforations corresponding to four revolutions of the sprocket, and to approximately the foot of film. Sometimes the shrinkage of the film is taken into consideration also.

There is a saving clause. The film does not entirely or even half envelop any sprocket in its passage through the machine. It only covers a small arc of the circle or circumference of the sprocket. It is therefore a matter of less moment to have the film exactly corresponding to the pitch circle, than if it passed completel yor nearly completely around the sprockets.

Leader and Trailer of the Film

There should be some feet of film without pictures at the beginning and another such piece at the end of each film. If there is not, then several inches of film, perhaps a foot or more is wasted in the distance from gate to bottom reel. Again at the top the motion should cease before the end of the film leaves the upper reel. Here would be a second section of wasted film if the film were printed from end to end. The piece of film preceding the pictures is called the leader; the piece at the end, after the pictures have ceased is called the trailer. The Society of Motion Picture Engineers have recommended that each film shall be provided with a black leader and with a red, green or blue trailer. Why black is stipulated for the leader, while there is the choice of three colors for the trailer is not divulged in the report, from which this recommendation was taken.

PERMISSIBLE PULL ON THE FILM IN THE OPERATION OF THE MACHINE

The take-up we have seen is a frictional device to regulate the pull on the film, as it enters the lower magazine and is wound on the reel within it. The same Society has concerned itself with this pull, and stipulates that it should not exceed fifteen ounces for a ten-inch circle. This is the circle determined by the film as wound on the reel. The diameter of this circle is constantly increasing, as the film rolls upon the reel. A high tension would operate to wind the film more closely, than a lower tension would, and the above tension is considered an advisable figure to follow in practice. If the film on the power reel increases to eleven inches in diameter an extra ounce of pull is allowed.

THE DANGER OF THE FILM IGNITING

The film moves in the space between the fixed aperture plate, and a perforated shutter or little door; the fixed aperture plate is behind the film, between the film and the lamp. The light from the lamp, as far as its use in the projection of the pictures is concerned, has to go through this aperture. The aperture is 29/32ds inch wide and 22/32ds inch high. It is quite surprising to realize how small is the picture, with which the work is done. On each side of the aperture are smooth vertical strips of metal, over which the film moves in the operation of the machine. Hinged to the plate or front of the machine, is a perforated plate, its perforation is of the same size as that in the aperture plate. It closes over the aperture plate; on each side of its aperture are also a pair of vertical strips of metal. When the gate is closed these strips come exactly over the corresponding strips on the face of the aperture plate. They nearly touch the strips, but a sufficient space is left between the two sets of plates for the film to pass without friction. Across the top of the aperture and below it there is also room left for the passage of the film.

DANGER OF FIRE OVERESTIMATED

Thus it will be seen that the film is surrounded by metal on all sides, front and back, except for the portion being projected. A film will rarely if ever catch fire while the machine is in motion. If something happens to stop the machine, and if the fire shutter fails to operate and if the operator fails so utterly in presence of mind as not to force it down and to close the dowser, the film will after a period of a few seconds catch fire. The combustion is not very vivid. It is without much flame and not very rapid. The film is so encased in metal framing, as described, that there is little chance of the flame or ignition extending beyond the area of a single picture. The cold metal surrounding the film extinguishes it. This action is somewhat on the lines of the Davy safety lamp used by miners.

Ignited Film in Operating Machine

There is no doubt that if the film ignited while the machine was in operation, drawing the film at the rate of a foot a second through the gate, the fire might be carried down outside the limits of the aperture. Then it would spread and run along the film and get into the magazine at the bottom of the machine and make a disagreeable fire there. This would be bad for the mechanism of the head of the machine. But there would not be the least danger of a conflagration. The fireproof booth, and the very fact that the magazines are made of steel acts to confine the effects of the most violent fire to two effects—one is to damage the machinery, and the other is to frighten the audience. The populace have been carefully trained to fear the effects of a film fire, and if such occurs the effects of that education may manifest itself in a senseless panic. The fire it is fair to say can do no harm to anyone. It is a misfortune as far as the delicate machinery is concerned only; it can do no harm to any person. But the panic may do harm, and it is a fortunate thing that all of a film, which will burn under ordinary circumstances is smaller in area than a postage stamp.

Precautions When Machine Stops Working

The instant a machine stops working the operator should shut the dowser; the fire shutter, if it has not been neglected and allowed to become gummed up and sticky, will also shut; the film will burn, not so very fast over the exposed half inch of area, and the first efforts of the operator after he has shut the dowser should be to light the room, so as to set the people at ease. But it is hard to know what to do with a crowd of people in a panic.

It is a pity that our legislators have educated and trained the audience to be ready to rush for the doors, when a piece of film as big as one's thumb nail ignites and burns rather slowly.

The Lamp and Film Fires

The danger incident to the film catching fire and almost exploding has exercised the thoughts of legislators to a considerable extent. The film may be termed a variety of the explosive, gun cotton. If ignited it burns with great energy, but does not explode. A bit of an old film can be thrown into the fire to show just what its combustion is like.

The heat of the lamp is concentrated on it by the condenser just as the heat of the sun is concentrated by a burning glass. The security from fire is in the motion of the film. Any given part of the film is exposed to the heat of the lamp for a small fraction of a second. It is less than the sixteenth of a second at normal speed of action, because of the obscuring of the light, if an inside shutter is used. This shutter cuts off light and heat during the periods of obscuration, and in this feature it is advantageous. But in this country the outside shutter is in universal use.

The outside shutter in its obscuring of the picture, as far as it does anything in this direction, increases the heat. It is only a trifling increase however.

With the outside shutter the film is exposed to the heat of the lamp for one-sixteenth of a second in normal running. There are the sixteen exposures to the foot to be made and the standard speed of the film is one foot a second. During part of the time the film is in motion, but that does not affect the average time of exposure to the light and coincidently to the heat of the lamp, concentrated on it by the condenser.

Ignition of Film Due to Stoppage of Machine

If for any cause the machine ceases to work and the film remains stationary it takes but a few seconds for it to become so hot as to ignite and start burning. The time is put by some authorities at four or five seconds. This it is evident is a small margin of safety.

PROTECTION OF FILM FROM IGNITION

The film is now so surrounded and framed in metal that if it does inflame the center of the film alone will burn, a hole thus being made through the film, leaving the edges intact. As the only danger to be apprehended from a burning film is the panic of the audience, if the combustion can be restricted to less than a square inch of thin film, the vividness of whose combustion is restrained to some extent by the gelatine emulsion which carries the pictures on it, would not seem adequate to frighten a theatre full of people. But from every standpoint the burning of any part of the film is to be avoided by every possible precaution. It is better to provide for its prevention than to rely on the safety devices to prevent it doing harm, when it occurs.

An operator will take the ground that a film will never do more than burn out in the center. This is a comforting idea, but it is better to contemplate the possibility of the whole film going off in a half explosion, half combustion, and to take measures to make the ignition of the film as nearly impossible as can be done.

THE FIRE SHUTTER AND THE FILM

The usual way of guarding against long exposure of the film to the heat of the projected rays is by a shutter hinged at the top, which is held up, so as to leave the path of the rays clear, by a centrifugal mechanism. This operates to hold the shutter up and out of the path of the light as long as the handle of the machine is turned. If anything operates to stop the progress of the machine and thereby to arrest the progress of the film, so that it is stationary, the centrifugal apparatus ceases to work, and the shutter drops between film and condenser, cutting off all heat from the film.

The construction of this type of fire shutter will be given in some detail a little later, with some prominent constructions as the base of the description.

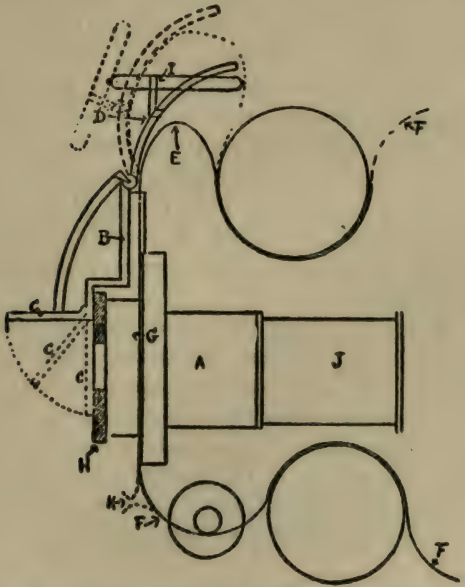
It will be seen that the centrifugal shutters, as they may be called, operate entirely by the motion of the machinery of the projector. But there is a case of exposure of the film to the heat, which may occur without the motion of the projection apparatus being arrested.

Breakage of Film Below the Gate

The film is fed by being pulled down from the bottom of the gate or frame. It may happen that the film under the strain will break below the gate. The machinery may keep on turning, if electrically driven it will keep on until the current is turned off, but the film will be motionless in the gate, exposed to the full radiation of heat from the lamphouse. If the light is not shut off or extinguished the film will almost inevitably catch fire. If there is a centrifugal fire shutter, it will not fall as long as the machinery is in action.

The Urban-Joy-Harris Anti-Firing Device

This is a case not taken care of by the ordinary type of fire shutter. The Urban-Joy-Harris anti-firing device, illustrated in the diagram provides for this emergency.



THE URBAN-JOY-HARRIS SAFETY APPARATUS

The shutter, C, is held in the position shown in the full lines, as long as the flap, D, is in the position shown also in full lines. The short lever arm at the foot of the flap, D, with the connecting piece as shown, holds C in a horizontal position. A glass tube, T, contains mercury. It operates as a sort of counterweight, and also when in the full line position, makes an electric contact through which the lamp current passes. The film passes through the frame at G. It may break at a point, F, below the opening of the gate. The machine may keep on turning, so that if there was a centrifugal shutter, it would not operate in this case.

In the operation of a projection machine the upper reel is constantly supplying film as the same is pulled along on its path by the upper sprocket. If the film breaks as described at the point, F, the regular loop at E will be enlarged instantly. In one second a foot of the film will be fed to it. This will force it up against the flap, which flap will be pushed forward into the position indicated by the dotted lines. In dropping forward into the dotted line position, it will drop the shutter, C, down in back of the film, cutting off from it all light and heat. The tube, T, also tips forward and the mercury in it, owing to the change of position, as indicated by the dotted lines, cuts off the current.

This apparatus takes care automatically of the accident of a film breaking below the gate. This is the place where the film is subjected to the greatest strain, and the most likely breaking point, but not the only one. The apparatus might fail to take care of some breaks.

One authority in describing this safety device, takes the ground that the centrifugal shutters are not to be recommended; that it is part of the duty of the operator to shut off the light the instant the machine stops. As there is a tendency to use the electric power to turn the machine, the instinctive turning off of the current by the operator is not to be implicitly relied on.

In this country the centrifugally operated fire shutter is generally accepted as representing the best practice.

CHAPTER XV

THE SHUTTER OF THE MOTION PICTURE PROJECTOR

THE story of the shutter and of its development, of all the trouble, which has been experienced with it in the past, and of the many efforts, which have been made to have it do its work properly, to get rid of flickering, would be quite a long story. The function of a shutter is not only to make the picture and to obscure the field of view, while the picture is in motion, and while a new one also in motion is being moved into the field, but it is to abolish flickering.

Attempts were made in the early days of the art, before serious efforts were made to secure projection of the film pictures on the screen, to exhibit pictures of the moving type without any shutters. An intermittent light was made to act as shutter, which was but another way of attaining the same result, for an intermittent light is secured by the shutter, just as truly as it would be by opening and shutting the electric current switch. Then there is another possibility, possible from the theoretical standpoint, but entirely impracticable, and that is to have no shutter and no intermission of the light. If the shift from one picture to the next one could be made with lightning-like rapidity, it is conceivable that the longer exposure of the pictures, compared to the shifting period, would enable the eye to carry them over and not to suffer any flicker from the rapid change.

PROJECTION WITHOUT SHUTTER

This will never be done presumably, although the assertion that anything whatever will not be done some time or other is now a very unsafe statement to make, so much has been accomplished, which seemed impossible.

The interesting factor in the above supposition of a possible abolition of the shutter, is what effect would the very short exposure, we have assumed to represent the time of the shift, have on the human eye? There is a hint for some interesting experiment in physiology.

FUNCTION OF THE SHUTTER

The function of a shutter is to cut off the light from the screen, while the film is in motion. This is its primary purpose; a secondary purpose involved in the first is to prevent flickering of the image. To prevent the eye being affected by the alternations of light and darkness on the screen, it seems to be necessary that the alternations should be more frequent than is required for the simple alternation of the pictures, or else that the sudden change from strong light to full obscurity should be modified and reduced.

PERSISTENCE OF VISION

While persistence of vision is often stated as an exact or constant figure, the fifth of a second, it varies considerably with variations in the circumstances of lighting. The operations of the projection of intermittent images on the screen, although apparently adapted to the laws of persistence of vision, bring out an unpleasant effect upon the eye. This is counteracted by the non-flicker shutters.

FLICKERING

A surprising amount of thought has been expended in the past upon the problem of avoiding flickering. People objected to sitting in front of a screen, on which the projected pictures constantly flickered to what would now be considered a very serious extent, for the public has been educated to expect the best. The problem was difficult of solution, because its precise location and cause could not be definitely found. One cause was the inaccuracy of films. This cause persists, and a worn film flickers more than a perfect one because the successive pictures do not register, and are not projected on the precisely identical parts of the screen. Worn sprocket holes in the film will cause the trouble.

PRESENT CONSTRUCTION OF SHUTTER

The mechanical construction of the shutter has pretty well settled down into the radial wing type, although there are several other forms of shutter, which have had quite extensive use in the past. The simple two- and three-wing radial disc shutter is now the accepted form in this country.

While the persistence of an image upon the human retina may, under favorable circumstances, be taken as lasting the fifth of a second, the picture will be gradually fading all through this period. So what the eye receives from the projection on the screen is not a succession of even effects of light followed by sharply defined periods of darkness, but there is a series of waxing and waning effects, which have to be taken care of to avoid flickering.

Operation of Shutter

If sixteen pictures per second are being projected on the screen, and if for the shift one-half the period of exposure of the picture is allowed, the dark interval will be one forty-eighth part of a second, and the exposure will last one twenty-fourth of a second. The sum of the two fractions is three forty-eighths or one-sixteenth of a second in accordance with the conditions as stated of sixteen exposures per second.

The way to bring about this obscuring of the screen would be to have a single blade on the shutter of 120° angular extension. This shutter would be revolved in synchronism with the film motion, one revolution to each picture projected.

Under these conditions it is found that persistence of vision is not enough to give an even effect. The eye will feel the variations.

The Flicker Wings of the Shutter

At an early period of the industry a second intermediate blade or wing was introduced; this was placed opposite in angular position to the obscuring blade. It was sometimes partly transparent and colored. The effect was to dim the picture a little, by cutting off the light during part of the projection period. This is a bad feature, yet it is found to be an advantage if it gets rid of the flicker.

The single auxilliary wing did not answer the purpose fully, and eventually three blades were tried, and this represents one of the modern types of shutter. One blade is an obscuring blade, the others are anti-flicker blades.

Position of the Shutter

The position of the rotating disc shutter may be in front of the objective or behind it. The latter class work between the gate aperture and the film and as close to the film as possible. In this country the shutter generally rotates between the objective and the screen, close to the face of the front lens of the combination.

INSIDE SHUTTERS

The Kamm shutter is an inside shutter. It has a single blade, and so as to secure the non-flicker effect, it is geared to rotate three times to a period instead of once. Thus the single blade does the work of three.

The Gaumont Chrono shutter is also an inside shutter with one wing; it is geared to rotate twice for each picture projected, thus giving the effect of a two-winged shutter.

THE THREE BLADE OUTER SHUTTER

In this country the three blade shutter in front of the lens, making one revolution for each picture projected is the rule.

There is one advantage to be looked for in the rear shutter. It comes between the film and the lamp; it therefore operates to cut off a considerable amount of the heat. A shutter inevitably cuts out a large proportion of the light. It seems a pity, since it has to do this, that it should not be made to do the same for the heat. The reduction of the light is a misfortune; the reduction of heat is a benefit.

THE SETTING OF THE SHUTTER AND TRAVEL GHOST

A shutter has to be correctly set. It must mask the light just at the instant the film begins to move, and must cease its obscuring the instant the next picture is in the field and the film is stationary. When the shutter is wrongly set, it will be because it cuts off the light beam too soon or too late. In either case it will affect a picture on the screen, while it is stationary and fixed in position. The result is that bands of light will appear on the screen. These bands will travel up or down, and are called travel ghost.

If the shutter obscures the light and ceases doing so at the exact period when it should there will be no travel ghost occasioned by its action. It is said to be in phase by some writers, when it is so set as to operate perfectly.

The Setting of the Shutter

There are several ways provided in different machines for setting the shutter. All the methods are based on turning the shutter either on the shaft, or with the shaft, so that its wing will cut off the light properly. In one method the bearings of the shaft of the shutter are loosened enough to permit it to be taken out of the engagement with the gear-wheel, which turns it. It then can be rotated shaft and all and be dropped back into position along with the shaft, the gear-wheel on the shaft entering again into engagement with the driving pinion.

The Simplex projector has an arrangement by which the position of the shutter blade can be changed while the machine is operating. The change is effected by turning a hand-screw. Some authorities do not consider this a good arrangement, as it gives too much temptation to keep at the adjusting of the shutter wings; if they are once right, there seems to be no reason why they should not be left so. Yet there is something attractive in the idea of being able to adjust the shutter, while the projector is in operation. It facilitates the operation and ensures the accuracy of the setting.

In other shutters the blades can be loosened from the hub by loosening set-screws. The adjustment can be completed with these, only while the machine is motionless. The operation requires but a few minutes.

The next problem is to tell when the shutter is correctly adjusted. The general rule is that the obscuring wing should intercept the view as long as the film is in motion.

An incandescent lamp is placed in the lamphouse and is lighted. The arc cannot be used for this test, because it would be too powerful. A film is threaded in the gate. If now the shutter is turned, it will turn the whole mechanism and the film will move as in the regular operation of the machine, but very slowly. The dowser is to be open and the safety shutter to be raised and kept so by a bit of stick.

The operator looks through the objective as he turns the shutter. He can watch the motion of the film or rather the effects of its action. If the shutter permits him to see the film when in motion, for even a small part of such motion, the shutter is wrongly set. It must be set again so as to cut off the view as long as the film is in motion.

Angular Position of Blades of Shutter

It may fail to do this because the angular position of the blade is wrong. If this is the reason the blade must be set and reset, if necessary, until the shift period of the film is completely hidden from the eye as it looks through the objective.

Width of Shutter Blades

If the motion of the film, after every effort at adjustment, is seen at the beginning and end of the shift, there is a possibility that the blade is too narrow. It is almost a certainty. The proper way of treating this trouble is to get a wider wing. Otherwise the wing may have some black- so-called needle paper, fastened to it with Page's glue or with siccotine, and the edge of the paper, extending over the edge of the blade, must be trimmed until the right width is attained.

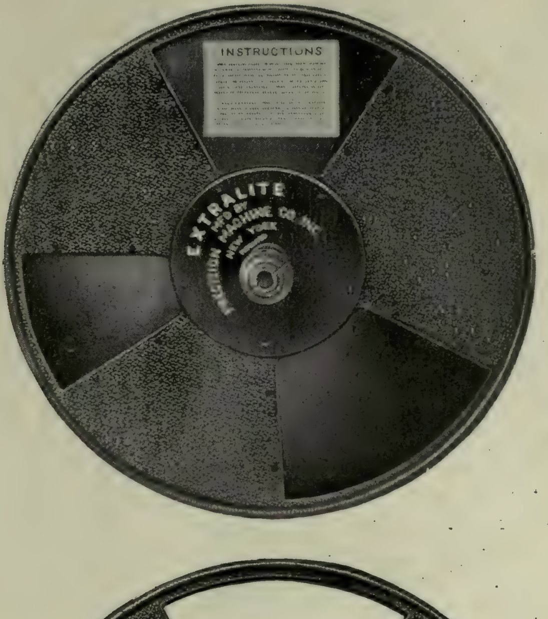
It will be a simple matter to ascertain by inspection what provision is made in any particular shutter for adjustment.

Synchronism of Shutter and Cycles of Alternating Current

If an incandescent lamp is supplied with alternating current, there will be a continual variation in intensity, as the waves change from zero value to maximum and back again. The variation is repeated as many times in a second as there are cycles in the same period. The more cycles there are in a second, the less in amount will the variation be. This is because the variation is due to the lowering of temperature as the current falls to zero. But the period allowed for this fall is a fraction of a cycle, or less than the sixtieth of a second, if there are sixty cycles per second. This number of cycles has become very general practice all over the country.

It has been found that with as few as twenty-five cycles per second the eye could perceive the change or flicker in an incandescent lamp. At sixty cycles the eye sees only a continuous light.

If a three-winged shutter is operating it produces forty-eight obscurings of the light per second. If the shutter is operated a little above this speed and if the cycles of the electric supply runs a little behind the proper frequency of sixty cycles per second, it is at least possible that an approximate synchronism of shutter


INSTRUCTIONS
EXTRALITE
MFD BY
PRECISION MACHINE CO. INC.
NEW YORK

THE SIMPLEX EXTRALITE SHUTTER

Flicker is eliminated because the picture is never completely off the screen, as some light passes through the perforations in the shutter-blades.

action and of frequency of cycles might occur. As the light diminishes to some extent at the change of polarity of the circuit, it is evident that this synchronism might increase its bad effects. Quite a point is made of this possibility by some authorities.

As the frequency of the cycles and of the obscuring by the shutter approach each other in numbers a change in the light may be noticed, an up and down variation in intensity, resembling that of two strings on a musical instrument, which are nearly in tune. As two such strings approach correspondence of frequency of vibrations, what is known as beats begin to occur, quite rapid when first perceptible, then as the two strings get more and more in accord the beats diminish in frequency, until the strings are in perfect tune. This phenomenon may be noticed when a piano is being tuned, and the tuner is often guided in his work by these beats.

It is precisely such beats as these which are produced by the joint action of the three-winged shutter and the sixty-cycle a.c. arc lamp. Complete synchronism may bring about considerable obscuring of the illumination.

If we think of the light of the arc being due to the ignition of the heavy carbons of the lamp, it would seem impossible for their incandescence to diminish perceptibly in the sixtieth of a second, and it seems as if something was missed here by investigators of the voltaic arc action. The fact that this diminution does occur is proof that there must be some very minute part of the carbon, which is mainly responsible for the light of the arc. It is easiest to picture the crater as giving the light from an immeasurably thin layer of carbon, which can cease to give its normal light, if the current drops in intensity for even so small a period as one-sixtieth of a second.

On account of this synchronizing action two-winged shutters, those with two wings instead of three, are sometimes recommended for use on sixty-cycle a.c. circuits. The best way out of the annoying trouble is to use a converter and supply the lamp with d.c. current.

RADIUS OF THE SHUTTER

The proper diameter of the shutter is indeterminate, because theoretically the greater the radius or the diameter of the shutter is the better it will be. The wings of the shutter have a triangular shape, and their outer portions have to cover a rectangular opening, the gate or its incipient projection. The diagram shows that to do this the segment or wing on a shutter of small radius would have to be of much greater angle than the corresponding wing on a shutter of large radius. A shutter of small radius might easily have wings of twice the angular value of those of a larger shutter. The light cut off is in proportion to the angular value.

Distance of Shutter from Objective Lens

The distance of the shutter, if of the outside type, as they generally are, is put at half an inch from the front of the objective. The objective must be adjusted in or out, and the shutter set one-half inch in front of the glass of the lens. This is considered to give a good general rule to be followed.

A good practical rule is to rotate the shutter while the light is falling on the screen. This rule is based on the crossing of the rays of light in front of the objective. As the shutter is rotated the shadow cast by it on the screen is watched. If the shutter is so close to the objective as to be inside the crossing of the rays the shadow thrown by it on the screen will follow the direction of its rotation. If the shutter is beyond the crossing the inversion will cause the shadow to move in the opposite direction to the motion of the rotating shutter. The correct place is taken to be between the two places, as near the point where the rays cross as is possible. A few trials will determine this point and the shutter may be fixed at that place.

This method of determining the place for the shutter is based on the assumption that the rays of light carrying the projection cross at a point outside the objective. If the objective is so constructed that the crossing of the rays takes place inside the tube, which carries the lenses, it is manifestly impossible to do as described. Then the alternative is to place the shutter as near the front of the lens as practicable. Here the half inch rule will apply.

With an inside shutter the crossing point of the rays does not ever apply, because they always cross in front of its position. For long throws at least, the cone of rays to be cut off by an inside shutter will be of larger diameter at the point of shutter action than when the outside shutter is used.

Dynamic Balance of Shutter

The shutter should be in as near perfect dynamic balance as is possible. It has to rotate so fast that if uneven in shape and balance it may shake the projection end of the machine, so as to make the picture on the screen unsteady.

The easiest way to get a rotating body such as a shutter into dynamic balance is to make it of perfectly symmetrical shape. There is a very common misapprehension about dynamic balance. If a wheel or other rotating body is to rotate without any shake or vibration, it must in general terms be so constructed that each radial portion shall have the same moment of inertia. Without going into mechanics, we may say that this means that the product of the weight of any radial portion multiplied by the square of the distance of its center of gravity from the axis shall be the same for similar widths or angular segments.

Static Balance of Shutter

The directions are given to test a shutter for balance by taking it off its shaft, threading it on a rod and seeing if it balances indifferently in all positions. If it does this it is assumed to be in balance. But this is what is called static balance, and may exist while the shutter is entirely out of dynamic balance. A heavy shutter out of dynamic balance might be in perfect static balance, yet its dynamic balance might be so bad that it would produce a very bad shake.

The best rule to be followed, if a shutter is out of dynamic balance is to apply to the manufacturer to remedy the trouble. The operator can spend any amount of time on trying to rectify the trouble, with the full consciousness that if he does cure it, it will be by chance and good luck only. Putting the shutter on a rod and filing and putting on bits of solder to get it in equilibrium may improve it or may not.

The Barrel Shutter

There is yet another type of shutter, which though but little used should be described. It is the barrel shutter. It is of the rotating type, but its axis of rotation is at right angles to the axis of the projecting lens, or as it may be better expressed, to the optical axis of the machine.

The shaft of the barrel shutter is carried by bearings near the front of the objective. It is on a level with the latter. At its end nearest the objective there is a cross-arm, and on the ends of this arm there are two sections of a cylinder. As the shaft of the shutter rotates, these sections sweep past the objective lens, across its face, and in close proximity thereto. The cross-arm carrying the cylindrical sections is to one side of the objective; the cylindrical sections project so that they successively mask or cut off the objective with a perfect shutter action.

The disc shutter acts with a segment of a circle, where theoretical considerations would on its face at least call for a square-shaped shutter. The fact that the disc shutter is thus limited in shape, exacts a sufficiently large diameter to secure a virtually square shape of the obscuring segment. At its best it does not get this. The barrel shutter on the other hand does give the desired square shutter action. The metal plate is bent to the radius of the half cross-arm; otherwise the action is that of a rectangular plate. The curve may allow a little light to escape, but not enough to do any harm to the projection.

Advantage of Inside Shutter

There is one great advantage in the inside shutter; it cuts off a large percentage of the heat from the lamp. It operates near the focus of the condensers. It must cut off about one-half the light, on account of the one or two flicker blades. This the shutter does wherever it is placed. If it is an outside shutter it shuts off no heat in its rotation; if anything it increases the heat, to which the film is subjected, as it intervenes between the objective and the screen. This is, however, a quite immaterial amount. The point to be made is that it has no effect whatever in reducing the heat received by the film from the condenser beam.

But the inside shutter every time it cuts off light, which may be not far from a third of the time of exposure and shift, cuts off the same percentage of condenser heat. The film will be heated but two-thirds as much as with an outside shutter.

It would require but a little ingenuity to make an inside shutter operate as a fire shutter, so that it would always come to rest with a blade between pitcure and light, when the projection machine ceased to operate.

Both two and three blade shutters are now in use. One of the early attempts at disposing of the flicker was to have a second blade of violet color, through which some light could pass.

Some times a small incandescent lamp is placed in the head of the machine to facilitate shutter adjustment by giving a light to see the film picture by when arranging the shutter blades so as to cut off at the right time.

CHAPTER XVI.

THE SCREEN

IT is quite a common saying, that wrinkles in the screen do not matter. They do matter, if it is only on account of the looks of the screen before the projection begins. There is not the least trouble in avoiding them.

STRETCHING THE SCREEN

The illustration shows a method of stretching a screen without any frame, or roller. The cut is self-explanatory. On each side there is a rope, whose ends are sewed to the corners. Each rope is longer than the side of the screen. It passes through rings on the side, and forms loops at the corners. By straining at the four corners an even tension is put upon the entire area of the screen. There is no pole or roller to be provided, so both portability and the power of getting a smooth surface are obtained.

SMALL SCREENS

For small scale projections, and these have to be considered too, there are a number of screens of different material and of different systems to be had. Some work on spring rollers, giving the same effective straight line for the top as can be obtained by pole hangers. Some have dust proof cases to protect them in their journeys, some have black borders, and screens of the largest size are made up with brass eyelets for hanging. These run as large as twenty-four feet square.

MATERIAL FOR SCREENS

The material should be substantial. In some the pores are filled with what is supposed to be a reflecting substance. They may be backed up with a second layer of material, and made perfectly opaque by a coating of india rubber on the back. They can in such make-ups be folded without injury, and can be washed with soap and water.

PORTABLE SCREENS

A great deal of attention has been given to portable screens. High class projection can be given with portable apparatus. The providing facilities for this class of projection is a valuable feature of modern operation, for there is a demand for such work.

SHEET SCREENS

If a sheet is used as a screen it may be suspended in several ways. Large sheets of heavy cotton are used in many cases, where motion pictures are shown only one evening in a week or other period. Even in hanging these there is a right way and a wrong one.

An excellent way of hanging a sheet is to have a wide hem on its upper edge. Through this a straight pole or strip of wood is thrust. It must be perfectly straight and not bend. If a strip of oblong cross-section, such as one by two inches is used, place it with the long dimension up and down. If set flat it will bend. The pole must be a foot longer than the cloth is wide. Hang it at the proper height. There should be tapes sewed on the lower corners. These are to be used to draw it down to two screw-eyes, which must be screwed into the floor a little ways outside the bottom of the cloth. For a temporary mounting. this will answer every purpose.

If you find yourself with a sheet destitute of the large hem, safety-pin a lot of tapes along its upper edge and use these to attach it to the pole. Safety-pins may be used to attach the bottom tapes and any others, which it may seem desirable to have. Intermediate tapes at the centers of the sides may be useful to assist in getting a smooth sitting.

SMOOTHNESS OF SCREEN

Neglect nothing to make the cloth sit smooth. If the tapes are so badly attached that they put a wrinkle in it, it probably will be impossible to remove it by any stretching. The author once had this experience. A ring, which had been on the corner of the sheet had come off, and someone had passed the corner of the sheet through it and tied the ring on. This established a large wrinkle, which could not be disposed of. The ring was removed and properly stitched on and the trouble disappeared. In strange places it is well to be provided with needles and thread, tape, and a lot of safety-pins.

SCREEN SURFACES

The subject of the surface on which moving pictures are best projected has received a great deal of study. Other things being equal a smooth surface may be accepted as the best for a screen. It must obviously be opaque, if the picture is to be reflected from its surface to be seen by an audience in front of it. In some instances a translucent screen with the projection apparatus behind it, and the audience on the other side has been used. This is applicable to small scale projections, as in parlors of private houses. There is so much good in the idea, which is a very old one, that it is a subject of regret that it has not proved more available for large theatres.

TRANSLUCENT SCREENS FOR REAR PROJECTION

For such projection a screen may be made of artists' tracing cloth.

It will be seen at once where one of the difficulties in using it occurs. The lantern has to be well back of the screen, in order to get a good effect, and in order to have a picture of sufficient size, without having to use an extremely short focus lens. In a theatre the sitting space is the valuable area, and this area would be diminished if the screen had to be set far out into the main part of the room.

Where this form of projection can be used its effect can be enhanced by forming a sort of recess about it. This may take the shape of the proscenium of a theater, and will shade the screen, so that views can be shown with considerable light in the room. It is evident that very nice effects can be produced by the development of the surroundings of the screen on these lines. It might seem that the proscenium part should be black. It is found, however, that too great darkness around the screen is not advisable. There is nothing like a dark room to make any kind of projection succeed.

THE SURFACE OF SCREENS AND THE ANGLE OF SIGHT

For people sitting in front of a projected picture a smooth screen gives the best results. In a long narrow room, such as many of the auditoriums are, a smooth surface screen is unquestionably the best. In the early days of the art, many long narrow rooms were taken for the work. In rooms of this character the audience were restricted to a narrow segment, so that all saw the pictures from a very direct line of sight. For these places, where the angle of sight for most of the people was very small, a smooth screen was the best. It was also the most obvious one. Everyone in the house, with few exceptions, was virtually in front of the screen. For such a plaster wall, well smoothed down was ideal.

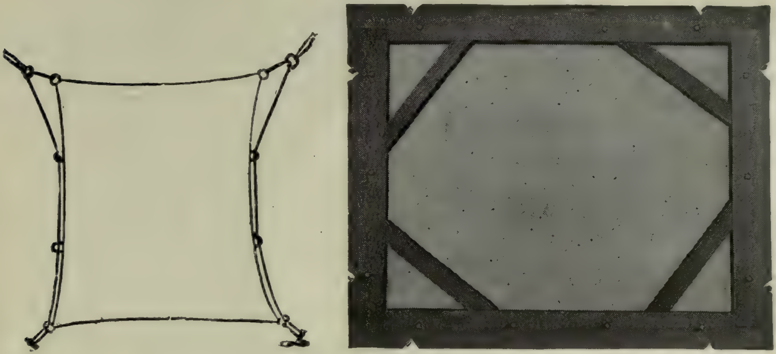
Of course for those in front and at the sides the angle of sight was very bad. They had to suffer, but were a small proportion of the audience. As moving pictures asserted more and more their sway over the public the wide auditoriums of theaters began to be used for their display. This at once developed new difficulties. Perhaps half of the audience saw the projections at an oblique angle. With a regular smooth faced screen, those at the sides were at a great disadvantage.

Varieties of Surfaces of Screens

Endless experiments have resulted from this state of affairs in the direction of producing a screen, which would show its picture as well to those seated to one side as to those in the center or axis of the house. A screen, which is of high reflecting power, and diffuses little light is economical of electricity, because a smaller candle power will give results, than when a rougher surfaced screen is used, which distributes the view to the sides of the room.

A smooth screen of high reflecting power, if used in a wide room will need a strong light to enable it to show the views to those in the side seats. The effect of this will be that the picture will be too bright for comfort for those in front. The glare produced will fatigue the eyes. To some the screen picture will seem much brighter than to others.

There is more than this to be noted. In the use of such a screen it may come about that one person may see an uneven light distribution on the screen. If the observer is near and to one side he will see the different parts of the screen under different angles of vision. His eyes will in general terms occupy the apex of a triangle. If to one side he may see part of the screen at a full right angle, and the most distant part may be at an oblique angle, so oblique as to appear much less brilliantly lighted than the nearer part. This inequality of lighting is wrong. It has to be coped with by the use of a type of screen, which will give higher diffusion. This involves a more powerful lamp, and more expenditure of electric power for its supply.



PORTABLE SCREENS

Almost every conceivable thing has been tried for screens. A mirror with ground or roughened face is one of the extremely bright screens which has been tried. This was for direct projection. Opal glass is another example of the extreme degree of brightness. A sand-blasted mirror, and sand-blasted metallic aluminum have been tried.

Jones' and Hillis' Paper on Screens

A very valuable paper on this subject was presented to the Society of Motion Picture Engineers at their meeting of October 11, 12, 13, 14, 1920. It was presented by Messrs. Lloyd A. Jones and Milton T. Hillis. They examined some thirty varieties of projection surfaces of the most varied description, using in the examination a specially constructed photometer. As a standard surface they selected magnesium carbonate. The light reflected by surfaces at various angles was photometered, the magnesium surface being taken as one hundred. The results are tabulated or given in curves or graphs. They are most instructive.

A sand-blasted mirror at an angle of about five degrees, had four times the reflecting power of the magnesium carbonate. But as the angle increased the light fell off with great rapidity so that at any angle over forty degrees it was of less than half the reflecting power of the standard.

The magnesium carbonate on the other hand between direct reflection and an angle of seventy degrees lost but one-quarter of its power.

Opal glass was exceedingly even. No screen, which started at a high degree of brightness at zero degree or direct reflection held its power; all such rapidly fell away.

Some of the most curious screens tried were bead screens. These were surfaced with beads, one with fine glass beads, the other medium sized ones. These started out rather high; the medium bead surface about two and a half times as bright as the standard. The smaller beads started at only eighty per cent. or no better than magnesium. But at only twenty degrees both had fallen to twenty-five per cent. below the standard, and held this with little change to the extreme limit of the experiment, seventy degrees.

The authors classified the screens by using the quotient obtained by dividing the reflecting power at the perpendicular by that at different angles. The figure thus obtained gave the value of the maximum reflecting power, that at ninety degrees in terms of that at the other angles. It was assumed that the greatest allowable difference might be taken at four. The poorest reflection must be at least one-fourth the maximum.

To this basis for selection was added the consideration of the average illumination within the range of angle taken in each case. With these two figures before him, the engineer can select his screen with some basis other than guessing at what he is getting in result. One figure gives the evenness of light, the other the relative expenditure of power required to operate the projection.

One very old suggestion is to use a sheet of linen or even cotton, with a mirror behind it. This is a little in the line of the sand-blasted mirror.

The aluminum painted surface, so extensively used, did not give very favorable results.

WIDE ANGLE AND NARROW ANGLE SCREENS

Screens may be divided somewhat as photographic lenses are. Some may be termed wide angle and some narrow angle. The selection of the best screen for a given room or auditorium amounts to the choice of a compromise. The subject has advanced so far now, that it is no longer to be taken as a matter of guess work; those who read the paper referred to will see how true photometric methods were applied to solving this part of the technique of picture projection.

The subjection of screens does not apply only to motion picture work. Whatever is said about them applies equally well to all kinds of still projection or stereopticon projection.

THE COMPROMISE SURFACE FOR SCREENS

The compromise element appears in the deduction from the investigation, that a gain in angle is accompanied by a loss in light.

THE LUX SCREEN

The Lux screens are an example of special surface quality, for the production of what we have called wide angle effect. They are made in two varieties. One side of the material is quite irregularily rough, being covered with little protruberances, in a sort of coarse grain. The other side is regularily corrugated or ribbed. The ribs, as they may be called are quite fine and strictly parallel to one another.

The interesting thing about this screen is that it is made in two varieties; one is for front and the other for rear projection. The material is thick and heavy, and resembles celluloid, except that it is flexible and can be rolled up like a piece of cloth. The rear projection variety is translucent, and is adapted for projection in daylight. There is no doubt that the projection in a dark room would be more brilliant, but with a good light in the lamphouse a fairly good projection can be had in daylight. If the material is held in front of a lens in the hand in an open room, any object in the focus of the lens will be quite distinctly projected upon it. Rear projection is little used, but there are cases in which it might be exceedingly advantageous, as in school or parlor projection. The corrugated surface of the screen we are speaking of has a dispersive effect, which is supposed to make the side seats in a projection room as good points of view as are the seats in front, or nearly in front. The front seats are sometimes objected to, but this screen is supposed to equalize to a considerable degree the quality of all positions from the spectators' viewpoint. The objection of the waste of space incident to the room required back of the screen for rear projection is a fatal one in many cases, but it is counterbalanced by the power to use the daylight hours for the work. The same material is made in an opaque variety for front projection, and what has been said about the equalizing all points of view applies to it also.

THE SO-CALLED KEYSTONE EFFECT

If the surface of the screen is not perpendicular to the axis of the beam of light from the lantern objective the picture on the screen will be distorted. As this distortion is generally due to the projection apparatus being too high and to the consequent necessity of tilting the apparatus with the front depressed, so as to give a picture wider at the bottom than at the top, it is thus termed not very consistently. Keystones are wider at the top than at the bottom. But as the distortion is between bottom and top in most cases, it will have to pass for a keystone upside down. This it represents very well.

The screen to give an undistorted picture should be set at such an angle that the imaginary line from the center of the objective to the center of the screen will be at right angles to the screen.

Sometimes it may be necessary to set the lantern to one side of the central line of the theatre. Then if the screen is square with the building or auditorium, distortion will appear. This too, is called keystone effect.

The proper cure for this class of distortion is to adjust the screen so as to have it perpendicular to the axis of the projecting beam of light from the lantern. A simple way is to use a cord or tape measure and by stretching it from the face of the objective to the four corners of the screen ascertain what must be done in the shifting of the screen to make the four measurements equal. When they are equal the screen will be at right angles to the axis in question, and the picture on the screen will be free from this kind of distortion.

Tilting and Shifting the Screen

Instead of measuring to the corners it may be easier to measure to the center of the sides of the screen. The screen is shifted if these are unequal, until they come out alike. The same is then done with the top and bottom. As in the case of the two side-lines, the measurements must be made to the center of the top and bottom lines. It is not only a question of avoiding distortion in these cases; if the tilting or swinging to the one or other side is excessive it may interfere with the focussing. It may be impossible to get all of the picture into focus at once.

Instead of measuring and adjusting by trial, it is a simple matter to lay out on paper the elevation or the plan of the lay-out of screen and lantern, and find by a scale drawing just what change in position of the screen is needed to make the setting square with the lantern.

For a screen to be shifted in this way it is almost necessary for it to be stretched on a frame, if the tilting forward or backward is required. For lateral adjusting the frame mounting is not needed.

Reshaping the Gate to Overcome the Keystone Effect

Another way of treating the keystone effect is to modify the shape of the gate. It may be filed out at top or bottom or side as needed, to give a true rectangle on the screen. This seems a poor way of getting at the trouble. Some even direct that the gate should be diminished in area by solder and then filed out.

When it is considered that the keystone effect interferes with focussing, it will be evident that the true method of correcting it is by adjusting the screen in the way described. It is far better to arrange for the location of the lantern in such a position that its projections will fall with axis perpendicular to the screen. It may also be the case that the keystone effect will be so slight as not to be noticed by the audience. If it is enough to be noticed it should not be tolerated, as it is so easily cured.

CHAPTER XVII.

THE PORTABLE PROJECTOR

THE full sized projection machine is quite large and is adapted to be set up in permanence in some hall or theatre where it is to remain. The illustrations show a portable machine designed to be set up and taken down on short notice; it is so light that it can be transported anywhere. The educators of the world are beginning to realize that the motion picture may be an important instrument of instruction; that it is not alone a thing to amuse; but that it can instruct as well. With such a machine as here presented a traveling lecturer can wander into the most remote places and show motion pictures in, what, practically speaking, is as good a way as is done in the largest auditorium.

THE HALLBERG PORTABLE PROJECTION

The plant includes the projector and an electric generator. The projector is carried in a case, and case and generator weigh about twenty pounds. Its dimensions are in inches, 8"x15 1/2"x 19". One of the cuts shows the box or case open to give an idea of the disposition of the interior machinery. It takes standard size and standard perforated film. It can exhibit a full reel, the regular one thousand feet.

There are now available many subjects in the educational field, some to be obtained from Government libraries and others from other sources. These are loaned out for use in the lecture field. Thus it can be employed for serious work.

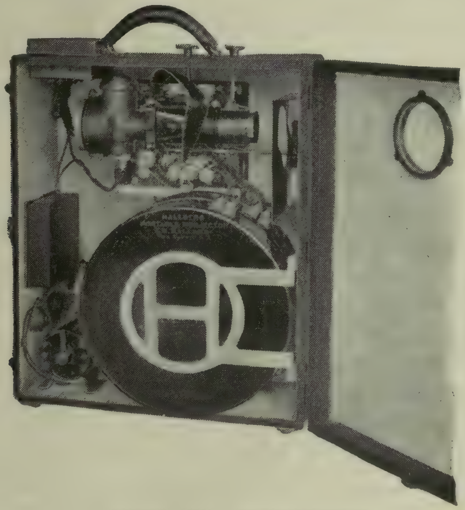
STILL PROJECTION WITH THE PORTABLE PROJECTOR

For still projection the same degree of illumination is not required as for motion pictures. The latter are on the screen for but a small fraction of a second, and the shutter cuts off a great part of the light. It is found that a still projection can be safely given with a light unit insufficient for motion projection. In the portable projector the light can be lowered by a governor, so as to make it possible to give still projection of any portion of the film. For lectures on serious topics it is evident that this might be most valuable. For instructional work it would be an extremely desirable feature. The action of the governor cuts down the light so that there is no danger of the film igniting or suffering injury, while the view is shown in motionless projection.

The cut showing the interior shows the accessibility of the machinery.

POWER PLANT FOR THE HALLBERG PORTABLE PROJECTOR

With the projector there is provided a miniature power plant. This is a gasoline driven engine actuating an electric generator. This is much heavier; the engine and generator and accessories weigh about ninety pounds. The plant stands fifteen inches in height, and takes for its base a floor space of seventeen by twenty-three inches.



PORTABLE PROJECTOR

The weight of the whole apparatus is put at a maximum of one hundred and fifteen pounds.

Gasoline can now be obtained anywhere. The little apparatus can be set up in a few minutes ready for projecting. The engine is necessarily of small size and power, so that it uses but a small quantity of gasoline; one pint will operate it for an hour. The suggestion is made that the plant can be used to light the hall or tent, as it may be, while the audience is assembling. It then can be diverted to its proper function of giving the light for the projection.

The apparatus is not dependent on the plant for operation necessarily. It may be considered as constituting two units; the projector and the plant for lighting the lantern. The projector can be supplied without the lighting plant, for use on local circuits. It is regularly adapted for 110 and 220 volt circuits.

Naturally it is not to be expected that portable outfits should give the results obtained with the standard apparatus. Yet it is claimed that pictures nine by twelve feet in area can be projected with sufficient brilliancy.

A motor drive with speed control is part of the outfit. This for the lecturer who is his own operator is of special interest.

All over the country the farms are now supplied with private plants. Out on the prairies, farm houses and offices are lighted by the electric light. The practice has become standardized to a voltage of thirty-two volts. The low voltage makes the storage battery do its work with a small number of cells. The portable projector is accordingly made in a third type, for operating at what may be called the farm voltage of thirty-two volts.

Courses of the Film in the Portable Projector

The course of the film in the regular full size projection machines has been explained and followed by the reader. The film travels in a straight line as far as lateral direction is concerned. It is more accurate to say that its travel is confined to one plane, as it comes out of one magazine and going through the machine passes through the gate and over rollers to the lower magazine, all lying in the one plane. To carry out this disposition of parts and direct travel of the film one magazine evidently must be above the other, not necessarily in the vertical above it but in the same plane and above the general run of machinery. In the Proctor automatic projector the upper magazine is directly above the other, one center in the vertical above the other. In other projectors the magazines will often set out of line with one another as regards the fore and aft position, but exactly in the same plane sideways.

It is evident that this arrangement is incompatible with the construction of a portable projector, if the reels in their magazines are to always occupy the same positions. The disposition of the two magazines in the portable instruments is side by side within the body of the instrument. Advantage is taken of the pliability of the film, to make it adapt itself in its course through the machine to this position of the reels in the magazine. By thus putting the magazines side by side instead of one above the machine and the other below it, compactness is gained so that the whole mechanism including the reels for full length of film is contained in a rectangular case; typical dimensions are those of the Hallberg portable projector.

A view of the interior of a typical portable machine is given. The position of the magazines in the lower part of the case is typical. The film is drawn from one of the reels upwards through the fire trap on the top of the magazine, and is fed upwards through the gate, then across and down again into the other magazine, being wound upon the other reel within the second magazine. If the path followed is studied out it will be perceived that the film has to make two right angle twists in its progress. It is no longer a simple direct line of progression but a line of travel including two right angle bends, each of which involves a quarter twist or right angle twist of the pliable film. This action is found to be perfectly practicable, and the portables give excellent results for smaller or even medium sized rooms. Thus with the regular size Acme machine a picture, ten feet in diameter can be projected at a distance of seventy-five feet, which is sufficient throw for the great majority of places.

In the Hallberg portable machine the light is maintained at full intensity by the motion of the machine through the action of a centrifugal governor. If the rotation of the sprockets ceases the current is automatically reduced, so that a diminished light is given, enough for a still projection. This is effected by the introduction of a higher resistance automatically when the motion stops. The reduction of light makes it safe to keep the picture on the screen for a minute or more without danger of ignition. This feature is considered a valuable one in educations work. There will often be certain views on the film, which it is desirable for the lecturer to have the opportunity of keeping on the screen for special explanation. The claim is made that a thousand feet of film used with this facility for delaying on special pictures is as good as four thousand feet run straight through without a break except that due to changing films.

Along with the Acme portable there is supplied a miniature generating set adapted to be mounted on the running board of an automobile. The automobile is now universal and carries with it a first quality motor, so the builders of the Acme machine utilize the driving engine of the car to actuate the projector.

Automobile Electric Generator for the Portable Projector

The automobile generator, as it is termed, is placed upon the right hand running board of the automobile. The rear wheel on the same side is jacked up off the ground, and a belt, which comes with the generator, is slipped over the rear wheel, is led under the idler of the generator, and around the pulley of the same. Next the generator is moved forward so as to get a sufficient stretch on the belt to be within the range of action of the idler. The engine of the car is started and put on high gear. The idler is made to bear on the belt enough to turn the generator at the speed corresponding to that of the rear wheel of the car. If the wheel in question turns at the rate equivalent to a speed of the car of ten miles an hour, the voltage of the generator will be brought up to one hundred and ten volts. The current from the generator is taken to the projector by a flexible conductor. As the generator only weighs forty-four pounds, it can be carried inside the car or on the running board or on the back on the tire rack.

The Hallberg outfit is shown in one of the views as packed on the back of a pack animal, as might be the case in Mexico. The Acme generator on the running board of an automobile is a good companion picture.

It is an important point in the use of an automobile generator that the rate of rotation of the armature of the generator should be constant, which makes it essential that the car should have an engine, which will run at constant speed. This being the case the speed of the car-engine is regulated in accordance with the readings of a voltmeter, which forms part of the outfit.

The portable projection machines are made possible by the use of the tungsten filament or Mazda lamps. These give so high a candle-power that they project pictures excellently for all ordinary sized lecture rooms. While for economical results it is necessary to run the lamps at full candle power, it is possible at the sacrifice of economy of trifling importance, to reduce the intensity of the light as much as appears desirable. This cannot be done with the arc light in the practical sense. The thick carbons do not cool instantly, the arc if not run at proper intensity is liable to give trouble, while the incandescent light in its bulb can be handled like a gas light, and can be turned up and down as required by changing the voltage. This may be done with a rheostat by changing the resistance, or it may be done by changing the speed of rotation of the generator.

Projecting with the Starting Battery of an Automobile

As the incandescent lamp is supplied of as little as six volts there is yet another way of operating portable machines. The starting battery of the car may be utilized to supply current. But if this is done it should be realized that it is severe service for the car battery, and the lamp should be of low power. It would be advisable to restrict the lamp to one or two hundred watts size. Even the smaller of these sizes would be a pretty good load for the battery. Although this use of the car battery is often spoken of it is fair to say that it is bad practice, and that the running board generator is always to be recommended in preference to the use of the starting battery of an automobile; the draught of even a fifty amperes incident to the supply of a three hundred watt lamp is too much to be taken from the usual starting battery; a one hundred and fifty watt lamp would be better, and might be used with comparative safety.

Portable Projection Booth

For portable projection machines a miniature projection booth, which can be taken apart for shipping from place to place, is manufactured. It is demountable. When put together it is carried on castors, so that it can be wheeled about from room to room as desired. The castors are rubber tired, so as to make its moving about quite noiseless. The booth is seventy-eight inches high, (6 feet, 6 inches), thirty inches wide and four feet deep. It can pass through any door. It is pointed out that this portability is an advantage in school work, as the booth can be moved from room to room as called for by the work in progress. The shelf for carrying the projector is adjustable for inclination; it has the two regular openings for the projection and for the operator to watch the screen through. There is a ventilating door at the top, and the two windows and this door shut automatically and instantly in emergency. The door is fitted with a spring hinge so as to shut of itself. The material of the booth is twenty gauge iron, black enamelled.

Finally it is to be observed that the portable instruments described are motor driven. The motor it will be observed has but one thing to do, which is to revolve the machinery; there is no need of a special motor for the lamp, because the lamp is an incandescent one and has no carbons to be fed. The incandescent lamp simplifies the problem here in a very special manner. It is not too much to say that the management of the arc light is one of the principle troubles of the work of projection. There are hopes that the arc will be supplanted by some of the news forms of bulb lamps, which are now being experimented with and some of which have been manufactured and put upon the market.

It is fair to say that the perfect high power lamp for projection is yet to make its appearance.

PROJECTING AT DIFFERENT SPEEDS

Moving objects may be photographed at one speed of exposed film, and may be projected at another. This fact enables the motion of various objects to be observed in a way impossible of attainment by any other process or method. Suppose the motion of the legs of a running horse were to be studied. The animal would be photographed on the sensitized film, at the normal rate of film travel of a foot a second. The film after development would give the effect of the motion of the horse, if projected on the screen at the same rate of a foot a second. But it might be that some particular part of the stride was to be examined. It would then be the obvious thing to do to stop the motion of the film and see the picture of the horse at the given moment while the film did not move. This leaves aside the question of the inflammability of the film, as it is only a hypothetical case. If such work was to be done special arrangements would have to be made in the way of protecting the film from ignition or individual lantern slides could be made from any part of the film selected.

This is given as an extreme case of the projection of objects in motion at a different rate of speed than the one at which they really moved. There are two phases of this division of projection. If a moving object is photographed at the foot a minute rate, a special and often very instructive effect is produced by a slow exposure. Owing to the inflammability of the film this process has its limitations. Its range can be extended by the photographer; he can turn the handle of the camera at higher speed, and so supplement the slow projection on the screen. In this way motion may be studied in a quite instructive way. But the method does not go far enough.

It may be extended on the following lines. By special arrangement and timing of shutter operation in the printing of the projection film from the negative, it is possible to print on the lantern film only a limited number of the pictures on the negative film. Thus the printing apparatus might be so arranged that every tenth exposure on the negative film would be printed on the positive film. This is obviously an incorrect way of procedure, for it involves the missing of nine-tenths of the action of the object. Yet it might be useful in the case of excessively slow moving subjects. In an extreme case the growth of a fungus might be the subject of a moving picture; the method outlined above would be entirely inapplicable, because of the waste of film, if for no other reason. Here the obvious way is to take periodical photographs on a film, a single photograph following the exposure by a long wait. If one exposure per minute were given it would require an hour of growing of the fungus to give the pictures for a five foot length of screen. At the normal rate the hour's growth of the fungus would be shown on the screen in five seconds.

Projecting the Motion of Slow Moving Things

By carrying out such methods the actual incident to the slowest moving objects can be studied. The screen and the motion picture becomes a true instrument of scientific investigation.

This species of exposure, covering it may be hours for a comparatively short piece of film, seems very tedious. Yet in the producing of animated cartoons, the same tediousness of operation appears. In the work of the "animator" the greatest patience is required, where an infinitesimal change in a pasteboard representation of a moving object is made by hand, an exposure taken, then a similar movement of the object by hand and a second photograph, and so on until after many hours enough feet of film negative have been produced for the desired effect and duration of picture.

The time required for such work is considerable and the poor results so often seen on the screen when animated cartoons are projected is due to the hurrying of the work, by giving too few exposures, with too much of motion for each one. This way of economizing on the time required for the tedious operation, as it is at its worst, for at its best it is still more tedious, leads to the jumping effect seen in animated cartoons on the screen. It may sometimes be the case that this very jumping is so comical that it is enjoyed by the audience, but it is very poor work, and is a return to the days when moving pictures were prepared for childrens' toys by hand drawings and were engraved and printed on a printing press. This is told about in the introductory pages of this book. It preceded the days of the application of photography to the subject of motion pictures.

SLOW SPEED PROJECTION

The idea of the serious production of photographs of moving objects at one rate of speed and of the subsequent projection of the film from the negative at another rate of speed, a much slower one, opens up a field of work in the study of the motion of slow moving objects, which is most valuable from the scientific standpoint. It enables really obscure problems of plant life to be investigated and to be so picturesquely presented that the public will be interested.

It should not be forgotten that the experience of the producers of moving pictures is that the public enjoy instructive pictures if they are adequately produced as regards both subject and quality.

It is simple enough to use plenty of patience and thus to secure pictures at long intervals of time, merged into a moving picture of greatly exaggerated speed of motion. But to do the reverse is not so simple. Here a hundred and sixty pictures may be taken in a second, to be projected at the rate of sixteen a second on the screen, so that the motion of quick acting machinery and of any number of other motions may be observed as if the motion was one-tenth as rapid as it really it. This is a very moderate reduction. By the use of the electric spark, pictures in great number in very small spaces of time may be taken and reproduced on the projection film for a rate of motion a hundredth or less of the real speed. Thus the French government used ultra-rapid photography to investigate the motion of projectiles and the outrush of the gasses from the gun as it was discharged. The special apparatus, which was employed took as many as 20,000 images a second, using the electric spark. The spark of the static discharge of electricity performed the functions of the shutter of the ordinary moving picture camera, with the inconceivable rapidity or rather frequency stated above.

The film in the camera moved at the rate of 328 feet per second, and when it was projected the speed was the standard one of one foot a second. It can be readily understood that a perfect opportunity for studying the action of a projectile is afforded when the rate of motion is slowed down to a small fraction of the original. We know so little about the real action of many things, simply because they move too fast for us to see what is taking place. But here the projector comes to the rescue. The film may have been taken at any speed within the limits of mechanics and of photography, but when it comes to projecting it on the film, the projection brings the speed down to so slow a pitch, that the eye can have presented to it the most difficult movements in clear and intelligible fashion.

Studying Efficiency by Projection

For the study of efficiency the ultra-rapid process is most practical and valuable. The work of the surgeon in cutting the tissue of the patient is repeated over and over as required on the screen with such deliberation that the motion may be only one tenth or less than the real in speed. In this way every motion of the master hand is made in the smallest detail. Machinery has been thus studied. The projection of the mechanism in motion at a slow rate of speed, so that every little feature of its action could be seen and studied at a rate enabling all the minute variations in its action to be appreciated, gives most valuable information as to what some piece of machinery is really doing. For it is fair to say, that we know little of the minute phases of the action of many mechanisms, simply because neither eye nor mind can follow them in their rapid action. The projection of such pictures on the screen gives most valuable information to guide constructors and manipulators of engineering constructions. It is fair to say that excellent work could be done in the study of the action of the moving picture machine by ultra-rapid photography. Familiarity does realize the wonder of what they are doing. Much could be made not breed reverence as a rule, and it is probable that few operators clear to the student of projection if the process were applied as suggested here.

In the internal combustion engine the all important thing is the cam action, by which the valves are opened and shut. The shape and timming of the cams is what makes a good or bad engine. The same projection gives the clearest enlightenment on the work of these members of the engine in question. The relation of their opening and shutting the valves to the positions of the pistons is most instructive if once known. The screen can be made to tell the story in projecting the action on the screen. The magnification as well as the slowness of the action is an element in the study.

Photography by the Electric Spark

The use of the electric static discharge spark to take pictures is a very refined piece of work. At present the mechanical camera is credited with one hundred and sixty pictures a second. This removes the work laboratory to the open field of everyday photography. Now it is said that there is a prospect of the rate of exposure being brought up to one thousand pictures a second and this on the standard film of the regular projection machine. In this way the study of rapid motion would be made most practical and its uses could be greatly extended.

Much of this applies more to the photography of objects than to projection. But the two work together, and it is hardly to be reckoned that we have strayed from our path in noticing this interesting phase of the work of the projecting of pictures. It would seem certain that much valuable work will be done in the future in these lines, so that the screen will be a very serious thing in the engineering and technical world.

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